LIARD RIVER HYDROELECTRIC DEVELOPMENT

IMPACTS ON MACKENZIE AND LIARD RIVER TRANSPORTATION

Report No. ESS-1 July 1981

PLEASE NOTE

The information in this document may be incomplete and is subject to amendment as a result of subsequent studies.

Prepared by: S.M. Hirst
M.J. Morgan

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PRELIMINARY

BC Hydro

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Canadian Cataloguing in Publication Data

Hirst, S. M. (Stanley Malcolm), 1937-
Liard River hydroelectric development : impacts on Mackenzie and Liard River transportation

Bibliography: p.
"Report no. ESS-1"
ISBN 0-7719-8949-0

1. Shipping - Mackenzie River watershed. 2. Shipping - Liard River watershed. 3. Liard River - Power utilization. 4. Hydroelectric power plants - Liard River. I. Morgan, M. J. II. B.C. Hydro. Environmental and Socioeconomic Services. III. Title.

HE635.H57 333.91'1 C82-092157-2

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SUMMARY

The potential impacts on Liard and Mackenzie river barging operations from hydroelectric impoundment of the Liard River within British Columbia are described and assessed. Both Scheme 2 and Scheme 8 operations and the period of reservoir filling have been studied.

The present Mackenzie River transportation system potentially affected by the Liard River hydroelectric project extends from Hay River, N.W.T. to Inuvik, N.W.T. and beyond. The Liard River system potentially affected extends from Fort Nelson, B.C. to Fort Simpson, N.W.T.

The bulk of present-day cargoes on the Mackenzie are carried by Northern Transportation Company Ltd., a federal crown corporation; smaller companies operate on the Liard and portions of the Mackenzie. Volumes of cargo, especially on the Mackenzie River, vary from year to year and are influenced to a large extent by the level of gas and oil exploration in the north. All major communities in the N.W.T. presently served by barge have at least one other mode of transportation link, usually air service and/or highway connection.

Barging operations on the Mackenzie would be affected to some extent by Liard hydroelectric development, depending on general hydrological conditions and on specific locations within the rivers. The navigation season through the San Sault Rapids, an historic problem area of shallow water, could be curtailed or extended by a few days under Scheme 2 development, depending on general water conditions. Under Scheme 8 development the period in which the San Sault Rapids could be negotiated could be increased by a few days. Under conditions of storage reservoir filling the navigation season through the rapids could be curtailed by up to 3 weeks. Navigational periods through other difficult areas such as the Ramparts Rapids or at Norman Wells would vary from the present non-regulated conditions by a few days at most.

The period in which the Liard Rapids on the lower Liard River would be negotiable by loaded barges would be curtailed under Scheme 2 operation by 1 to 6 weeks. Scheme 8 operation would extend the period by 1 to 3 weeks. Filling of the large Site E (Scheme 2) reservoir would curtail the navigation season by 3 to 7 weeks and, if the filling period coincided with a general low water year, might render the lower section of the Liard non-navigable for a season. Filling of the much smaller Site G (Scheme 8) reservoir would reduce navigation through the Liard Rapids by 2 to 3 weeks. Navigation on the reaches upstream of Liard Rapids would not be affected by either Scheme 2 or Scheme 8 river regulation, but may be reduced by 2 to 3 weeks during the Site E dam filling period.

A detailed evaluation of the effects of changes in ice regimes and spring break-up times on Mackenzie and Liard navigation will have to be deferred until 1982. A comparison with break-up times on the Peace River below the Portage Mountain Dam suggests that no significant delays in navigation will ensue.

SECTION 1.0 - INTRODUCTION

The Mackenzie valley waterway comprises the lower sector of the Mackenzie River watershed, and extends from the railhead at Hay River and Great Slave Lake, N.W.T. to Tuktoyaktuk on the Arctic coast, a distance of some 1800 km. The Liard River is the largest single tributary of the Mackenzie and is navigable by commercial traffic from the confluence near Fort Simpson to Fort Nelson, B.C., on the Fort Nelson River. Fig. 1-1 presents a general map of the Mackenzie and Liard navigation routes.

River depths are important constraints on navigation in the Mackenzie system, particularly within shallow rapids sections. Hydroelectric development of the Liard River within B.C. would change the present flow patterns in both the Liard and Mackenzie rivers and could thus impede or improve navigable river depths. Other potential effects of development on navigation would relate to changes in seasonal ice break-up which normally signals the commencement of the navigation season.

Four alternative hydroelectric development schemes on the Liard River have been identified. These consist either of a 2-dam arrangement with dams at Sites E and A or else some variation of a 3-dam scheme with dams at Sites G, F and A. Table 1-1 summarizes the main characteristics of each potential scheme. Scheme 2 is the presently accepted base scheme for Liard hydroelectric development.

The amount of water released from the Site A dam to the downstream Liard and Mackenzie rivers would differ between development schemes, mainly as a result of the different amounts of upstream storage available. Fig. 1-2 summarizes the mean monthly releases from Site A computed over a 30-year period, assuming a 60 percent capacity factor and an optimal use of the power generating facilities (Hydroelectric

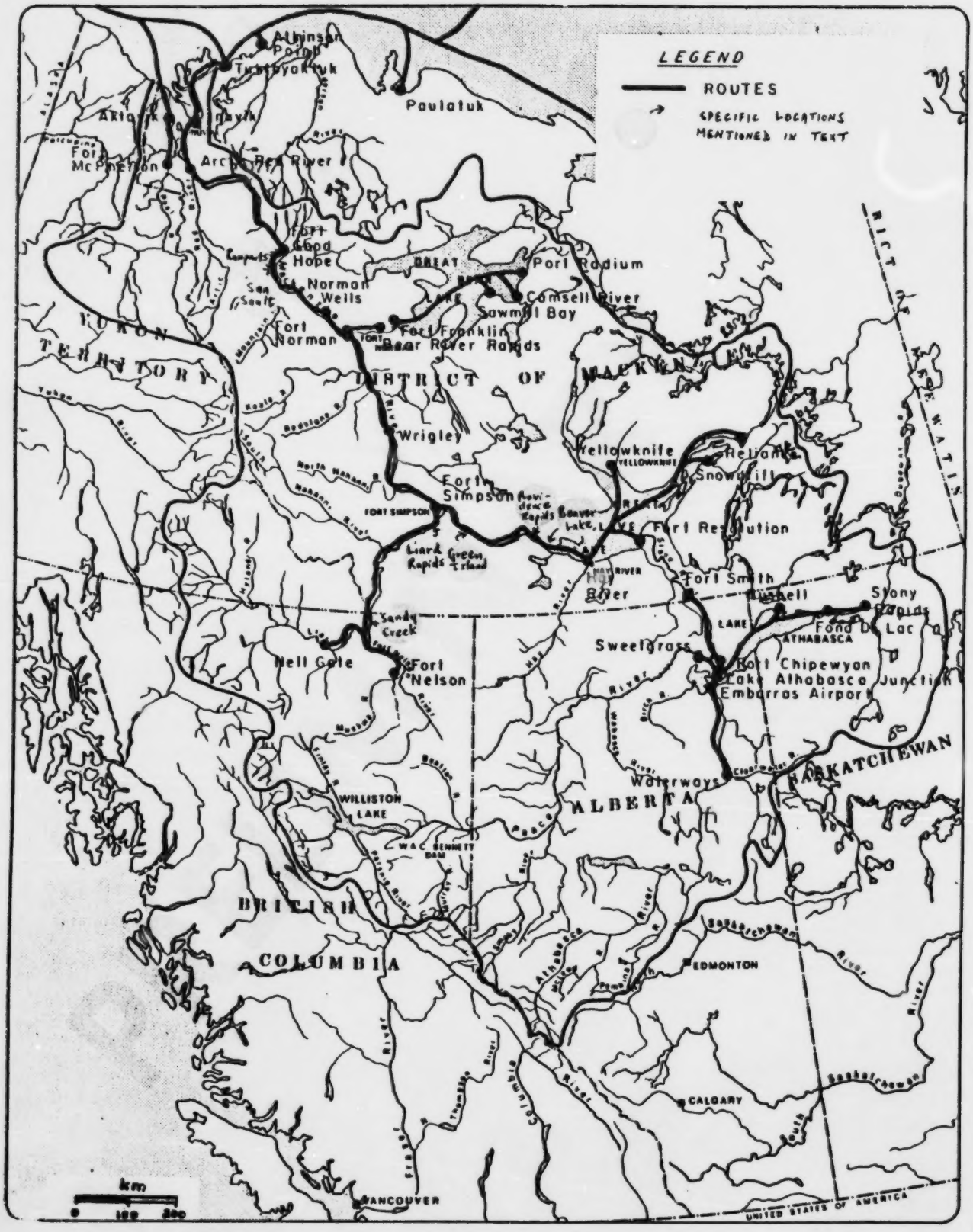


Figure 1-1. Mackenzie River System Navigation Routes (from Inland Waters Directorate, n.d.)

TABLE 1-1

ALTERNATIVE HYDROELECTRIC DEVELOPMENT SCHEMES FOR THE LIARD RIVER, B.C.*1

Scheme	Site	Maximum Reservoir Level (m)	Live Storage ($m^3 \times 10^{10}$)	Average Annual Stream Flow (m^3/s)	30-year Average Energy Output (MW)
2	E	572	21 000	1 100	1 630
	A	390	250	1 260	1 280
					2 910
7	G	625	11 700	680	660
	F	503	0	1 060	460
	A	445	2 600	1 260	1 760
					2 880
7A	G	610	9 000	680	560
	F	503	0	1 060	450
	A	445	2 600	1 260	1 740
					2 750
8	G	572	2 200	680	260
	F	503	0	1 060	290
	A	445	2 600	1 260	1 440
					1 990

*1 Data from Hydroelectric Generation Projects Division 1980a.

PRELIMINARY

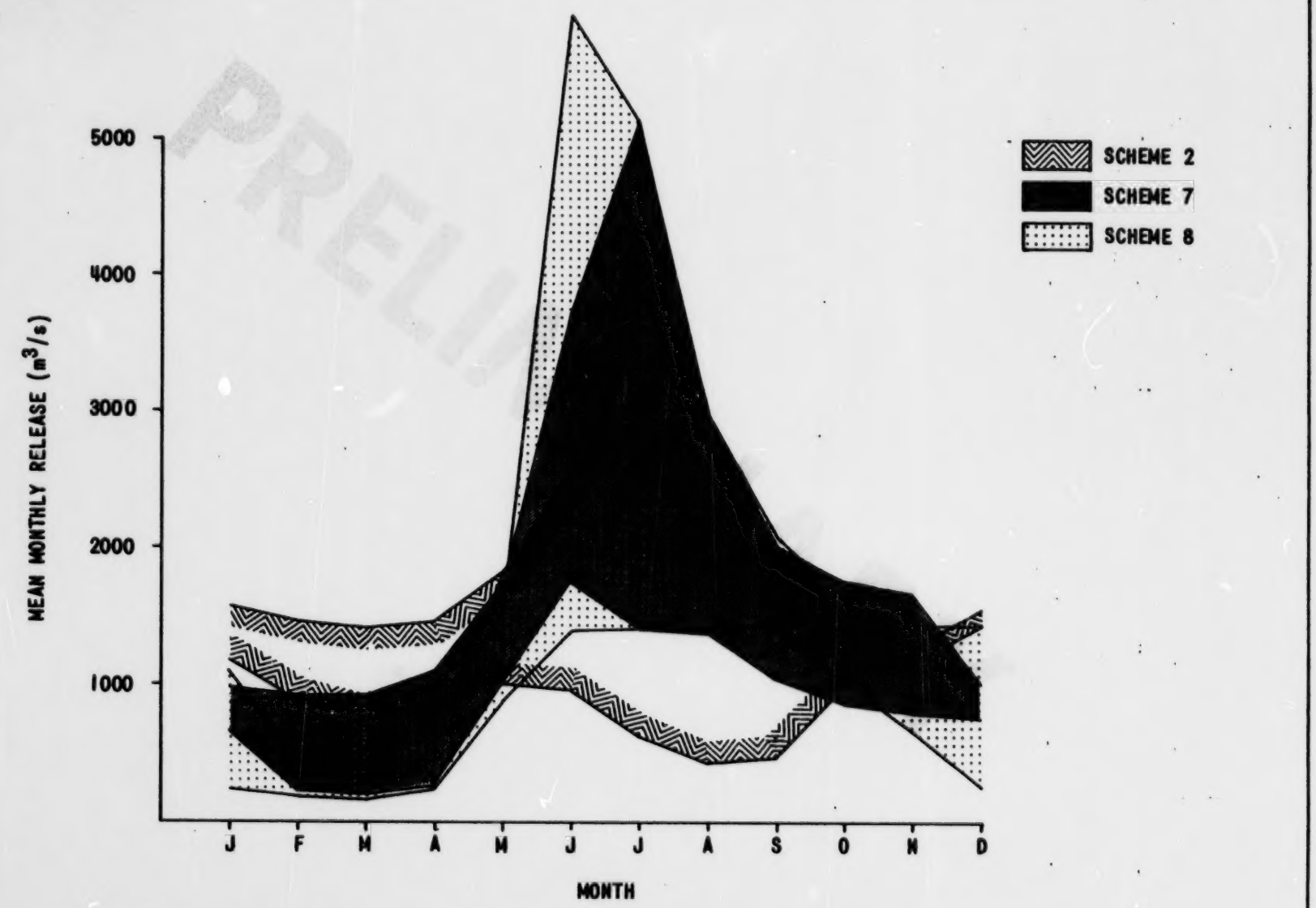


FIGURE 1-2 MAXIMUM AND MINIMUM MONTHLY MEAN WATER RELEASES FROM SITE A DAM FOR EACH OF THREE HYDRO-ELECTRIC DEVELOPMENT SCHEMES. VALUES ARE MEANS COMPUTED FOR PERIOD 1948-1977 (HYDRO-ELECTRIC DESIGN DIVISION 1979)

Design Divison 1979). Over a long-term period, Scheme 2 would be expected to produce the greatest amount of change in downstream Liard and Mackenzie river flows during the normal navigational period June through September. Scheme 8, with the least amount of upstream storage, would produce less change, with Schemes 7 and 7A being intermediate between these two.

The objective of this study was to review the present river transportation systems with special reference to low water and other hydrological controlling factors, and to predict the changes brought about by impoundment of the Liard River within B.C. The study commenced in August 1979 and was completed in June 1980.

PRELIMINARY

SECTION 2.0 - METHODS

2.1 RIVER TRANSPORTATION INFORMATION

All recent available information on commercial transportation use of the Liard and Mackenzie rivers was assembled and reviewed. Reports of major value included those relating to the proposed Mackenzie navigation channel improvements (Dept. Public Works Canada 1976, Renewable Resources Ltd 1978) and the Mackenzie valley transportation study (Swan Wooster Engineering Ltd 1972). A full list of reference sources appears in Section 7.0. Additional information was provided verbally by senior executives of the Northern Transportation Company Ltd., the principal barge operating company on the Mackenzie. Some information on social and economic aspects of transportation was probably outdated (e.g. Travacon Ltd 1973) but the general implications in these reports were considered to be valid.

2.2 ICE CONDITIONS

A detailed investigation of the impacts of Liard River impoundment on spring break-up and on winter ice formation in the Liard and Mackenzie river systems was initiated in December 1979 as part of the overall environmental studies program for the Liard project (Lasalle Hydraulic Laboratory Ltd 1980). This is expected to continue through 1981, and will provide a basis for determining whether changes in break-up could influence the navigational period.

Some provisional impressions of changes in break-up were obtained from an examination of ice break-up data from the gauging station WSC-07HA001 on the Peace River at Peace River, Alberta. The gauge is located approximately 340 km below the Portage Mountain (W.A.C Bennett) Dam. Daily observations made by the Water Survey of Canada (1979)

include the presence of "ice conditions" which create a backwater effect on the gauge reading. The disappearance of "ice conditions" in April or May provides a year-to-year comparison of the approximate time of break-up at that particular point in the river. Records for the station are available from 1958, i.e. 11 years pre-impoundment (Portage Mountain diversion closed in 1968) and 10 years post-impoundment records. The mean and median dates of such break-up for the pre- and post-impoundment periods were computed and compared by means of the non-parametric Mann-Whitney test (SAS Institute Inc. 1979). Similar comparisons were made for dates when "ice conditions" first appeared; this gave some approximation of the comparative freeze-up dates at that point.

2.3 LOW WATER CONDITIONS

River depths, widths, slopes, curvatures, current velocities, sediment loads, discharge characteristics and the nature of the bed and banks all affect navigation and navigational planning on the Mackenzie system (Dept. Public Works Canada 1976). Of these, water depth is by far the most important factor influencing navigation and the one most affected by flow regulation from hydroelectric impoundments. Low water levels of significance to navigation occur at many sites in the Mackenzie and Liard rivers (Dept. Public Works Canada op. cit) the most important being at the San Sault Rapids and the Ramparts in the Mackenzie (Dept. Public Works op. cit, Renewable Resources Ltd. 1978) and the Liard Rapids in the Liard River (Water Investigations Branch 1968). The study accordingly concentrated on evaluating the changes in water depths at these specific locations. In addition, the depths in the vicinity of the Norman Wells wharves were examined, this area being selected as typical of a barge loading and unloading point on the Mackenzie. Since barges using the lower Liard can orginate from Fort Nelson and use the river upstream of the Liard Rapids, an examination of river depths in this section of the lower Liard was also undertaken.

The 10-year period 1968 through 1977 was selected as a representative study period. Daily discharge records are available for this period for two representative flow gauging stations 10KA001 at Norman Wells on the Mackenzie and 10ED001 at Fort Liard on the Liard River (Water Survey of Canada 1968-1977).

Regulated flow regimes for the various hydroelectric development schemes have been calculated (Hydroelectric Design Divison 1979). However, these are presented as mean monthly values. Within the fall months river discharges measured at Norman Wells can drop as much as 34 percent from the beginning of a month to the end; at Fort Liard the monthly decline has been as high as 55 percent. It is apparent that regulated river flows could decline to significantly low levels within a month and yet the mean monthly flow could be above a critical level. It was thus considered necessary to compute regulated flows on a daily basis for those periods when water levels could become significantly low.

Daily regulated flows have recently been computed (Hydroelectric Generation Projects Division 1980b) using the SIMPAK routing model (Inland Water Directorate 1979). These were computed for Scheme 2 hydroelectric development only and not for any of the other potential schemes or for the period when the main storage reservoir would be filling. For this reason the regulated daily flows as estimated below were utilized in preference to the SIMPAK estimates, but a comparison of the two estimates was made.

Daily flows and depths were computed for the open water months, i.e. July to November on the Mackenzie and June to November on the lower Liard River. Mean monthly flows and depths were used for other portions of the year. Regulation under both Scheme 2 and Scheme 8 and during reservoir filling was evaluated. Schemes 2 and 8 represent the two extremes in Liard River regulation, with Schemes 7 and 7A being intermediate (see Fig. 1-2). The filling phase would be expected to last 2 years for Scheme 2 with an upper dam at Site E, and possibly less for Scheme 8 with a storage reservoir behind a low Site G dam.

Daily flows under operating conditions at the Norman Wells and Fort Liard gauging stations were calculated as

$$Q_{REGULATED} = Q_{NATURAL} - Q_{IMPOUNDED} + Q_{RELEASED}$$

Natural daily flows were obtained from Water Survey of Canada data tapes (1968-1977) maintained by Computer Science Division, B.C. Hydro. Impounded daily flows were taken to be those measured at the gauge on the Liard River near the Beaver River confluence (station 10BE005). A 1-day lag was assumed for the Fort Liard gauge and 5 days for Norman Wells (Hydroelectric Design Division 1979). The amounts of water released daily from a dam at Site A under operating conditions were computed from mean monthly releases by the use of a model. Further details are presented in Appendix A. The model simulated daily releases which, when averaged on a monthly basis, approximated the values computed to give the optimal power output from the reservoirs (Hydroeletric Design Division 1979). The simulation also provided for variation in daily releases, which would occur due to day to day change in load demand. Such variation was assumed to be relatively low, with a monthly coefficient of variation of approximately 10 percent (monthly coefficients of variation for Portage Mountain daily releases vary from 5 to 38 percent). Due to the long transmission linkage between the future Liard generating stations and the B.C. lower mainland, and the large power output from the whole scheme, it was assumed that the plants would be utilized for base-load generation with a low amount of day-to-day variation when they come on line in the 1990s.

Daily releases from the upstream dam (E or G) under filling conditions were simulated as

$$Q_{FILLING} = Q_{NATURAL} - Q_{IMPOUNDED} + Q_{MINIMUM\ RELEASE}$$

Natural daily flows were obtained as described above. Impounded flows were taken to be those measured at lower Liard crossing (station 10BE001) for Site E or those above the Kechika River confluence (station 10BE006) for Site G, with similar lag periods to those described above. The minimum release was assumed to be 280 m^2/s, which

was the minimum release allowed for the Portage Mountain Reservoir during filling in 1968 and 1969. This probably represents a low estimate of minimum releases for a future Liard River reservoir.

Two water level gauges are maintained by Water Survey of Canada at the San Sault Rapids and at Fort Good Hope (immediately above the Ramparts) respectively. All available data (Water Survey of Canada 1968-1977) from these stations were plotted against flows recorded at the Norman Wells gauge, assuming a 1-day lag in each case. Outlying data points were noted and discarded; these were assumed to have been caused by icing effects on the water level readings. Curvilinear (second degree polynomial) regression equations were computed for each flow: water level data set. These were then utilized as predictive equations for estimating water level readings at the San Sault and Fort Good Hope gauges, given a regulated daily flow at Norman Wells. Water levels at these stations were related to water depths at critical navigation points in the Mackenzie by reference to navigational charts prepared by the Canadian Hydrographic Service (CHS) (1979). For any point on the charts,

Water Depth = Charted Depth + Gauge Level - Zero Datum Correction Factor

Chart zero datum correction factors for relating chart readings to San Sault or Fort Good Hope gauge levels are given on the CHS navigation charts. Calculated levels for the non-regulated situation were compared to some historic records of difficult navigation (e.g. 1969, 1980) to check the accuracy of the predicted water levels.

Navigational charts are not available for the lower Liard River, and therefore a different approach to determining daily water levels was utilized. Two cross sections of the river (Underhill Engineering 1979), prepared as part of the studies on river morphology and winter ice regime, were selected. One traversed a typical section of the Liard Rapids, the other a section of the Liard River above Sandy Creek,

15 km south of La Jolie Butte within B.C. The latter was judged from aerial photographs to represent a typical portion of the river, upstream of the rapids, used by barges operating from Fort Nelson. For each section a curve relating depth in the main shipping channel to cross-sectional area was prepared. An estimate of current velocity through each cross section was calculated as Flow/Cross Section Area. Flow was taken as being equivalent to that measured at Fort Liard on the same day as the cross section was charted (assuming a lag time of less than a day between the cross section location and the Fort Liard gauge). Cross-sectional areas for each of the cross sections were then computed for each day for each natural or regulated flow from the relationship Area = Flow/Velocity, and depth in the shipping channel was then calculated from the respective regression equation. The flow velocity through the cross section would not have remained constant, but day to day variation would probably be low during the fall low water season. The estimates of depth would naturally be less reliable for the higher flow months of June and July.

Minimum permissable water depths for navigation were assumed to be 1.2 m (4 ft) for tugs negotiating the Liard Rapids or the Norman Wells docking area, and 1.5 m (5 ft) for tugs proceeding along the main shipping channels in the Liard and Mackenzie rivers (C.H. Kirkland Northern Transporation Company Ltd., personal communication). The rationale for these depths is given in Sections 4.1 and 4.2.

PRELIMINARY

SECTION 3.0 - RIVER SYSTEMS

3.1 GENERAL DESCRIPTION

The principle references used as source material for Sections 3.0 and 4.0 are Water Survey of Canada (1971), Swan Wooster Engineering Ltd (1972), Dept. Public Works Canada (1976), Renewable Resources Ltd. (1978) and Inland Waters Directorate (n.d.). Additional sources include Water Investigations Branch (1968), Inland Waters Directorate (1973) and Allen (1977).

The Mackenzie River and Great Slave Lake, contained in the Mackenzie District of the Northwest Territories, lie in the Mackenzie lowlands between the Canadian Shield and the Mackenzie section of the Rocky Mountains. The series of rivers and lakes which make up the drainage system have a total length of 4000 km from the headwaters of the Finlay River in the Rocky Mountains to the Beaufort Sea, and drain a basin with an area of 1 800 000 km^2. Mean annual flow exceeds 8500 m^3/s which is equal to about 17.5 cm of runoff over the whole basin. The Mackenzie itself is about 1712 km long and flows from Great Slave Lake to Mackenzie and Kugmallit bays of the Beaufort Sea.

The Mackenzie River drains a variety of terrains ranging from high alpine and parkland to rocky barriers and low muskeg. The major tributaries such as the Athabasca, Peace, Liard, Nahanni, Redstone and Keele rivers originate in the Rocky-Cassiar-Mackenzie mountain ranges, and provide the bulk of the discharge in the Mackenzie River. The Hay and Trout rivers drain parkland and muskeg regions, while the Taltson, Lockland, Yellowknife, Snare and Willow Lake rivers drain the Canadian Shield. Lake Athabasca (4896 km^2) and Great Slave Lake (17 872 m^2) provide storage for natural regulation of the Mackenzie. Low water datum for Great Slave Lake has been established at El. 156.40 (513.14 ft). During an average year, the lake attains its highest

level in the months of July, August and September, and the lowest level in April prior to the thaw. Great Bear Lake (19 200 km^2) provides extremely stable inflow to the Mackenzie at Fort Norman via the Great Bear River.

Annual precipitation is quite variable over the whole basin, ranging from more than 50 cm along the mountains to less than 25 cm on the Canadian Shield: rain provides 60 percent of this amount and snow provides the remaining 40 percent. Ice conditions are variable down the river and from year to year. In general, ice covers the Mackenzie completely for about 5.5 months with freeze-up and break-up taking around 2.5 months. About 4 or 4.5 months are open water for navigation.

3.2 DISCHARGE PATTERNS

Hydrographs for the Mackenzie River generally follow a specific pattern. During the winter period of ice cover, both stage and discharge usually decrease until about mid-May, when increasing temperatures and snowmelt runoff combine to cause spring break-up of the river's ice cover. Stage and discharge continue to increase during late May and June as a result of snowmelt and rain runoff in the Athabasca River and Peace River systems. July flows are also high as a result of rain and snowmelt runoff from the Cassiar and Mackenzie mountains. In mid-July the river begins to recede; however, this recession is interrupted periodically during August and September as a result of rainstorm runoff events occurring on various tributary basins. Minimum fall stage usually occurs in October just prior to fall freeze-up, after which stages, but not discharges, rise because of backwater caused by an increased build-up of ice cover. Stage and discharge then recede during the winter months, and the pattern is repeated the following year. Variations occur from year to year for the date of freeze-up and break-up, and in the time and magnitude of fall minimum, spring minimum, and spring and summer peaks (stage and discharge).

Low flows of significance to navigation can occur in May and early June prior to the major spring runoff and then again in the fall during the recession period. The spring low flows are normally not critical, since shipping from Hay River is usually delayed until mid-June by ice on Great Slave Lake. They are only of short duration prior to spring high water. The fall low flows are much more critical; they are sustained by the hot dry fall weather conditions and the resultant recession or lessening of flows. Cold weather in late September or October causes another drop in stage as water is diverted into ice production until ice frictional effects cause enough backwater influence to raise the stage again.

The Mackenzie River from km 0 (mi 0) on Great Slave Lake to km 325 (mi 204) near Fort Simpson is regulated by Great Slave Lake. The lake itself in any one open water season normally varies only about 37 cm in stage. If it were not for the occasional wind set-up and drawdown on Beaver Lake above Fort Providence and on Great Slave Lake, this river reach would exhibit a stable week-to-week flow. The river carries relatively little sediment.

At Fort Simpson the Liard River adds a variable and sediment laden discharge to the Mackenzie from the snowmelt and runoff in the mountains to the west. Proceeding downstream, the erratic discharge characteristic is magnified by further inputs from mountain-fed tributaries to the west. In 1976 the Water Survey of Canada estimated a flash flood discharge in the Mountain River at Sans Sault Rapids, km 1008 (mi 630) at approximately 4250 m^3/s. Normally, this river is an innocuous stream. Such flash floods in the past have jammed the 3.2 km width of the river at Sans Sault Rapids with debris. During the same month as the flash flood on Mountain River, the Water Survey of Canada reported an estimated peak flow of roughly 2830+ m^3/s on the Root River at km 370 (mi 295). Data obtained from dredging investigations (Renewable Resources Ltd. 1978) show that storms moving up the Mackenzie valley can induce a negative time lag in flood peaks proceeding down the river.

Fig. 3-1 provides some comparison of discharges in the Mackenzie and Liard rivers respectively in a typical year.

Great Bear Lake contributes a stable flow from approximately 397 m^3/s to 566 m^3/s (depending on the year) at km 821 (mi 513). It offers an insignificant contribution to the discharge in normal years but in a low water year in October it would account for approximately 16 cm of stage at Norman Wells.

3.3 ICE CONDITIONS

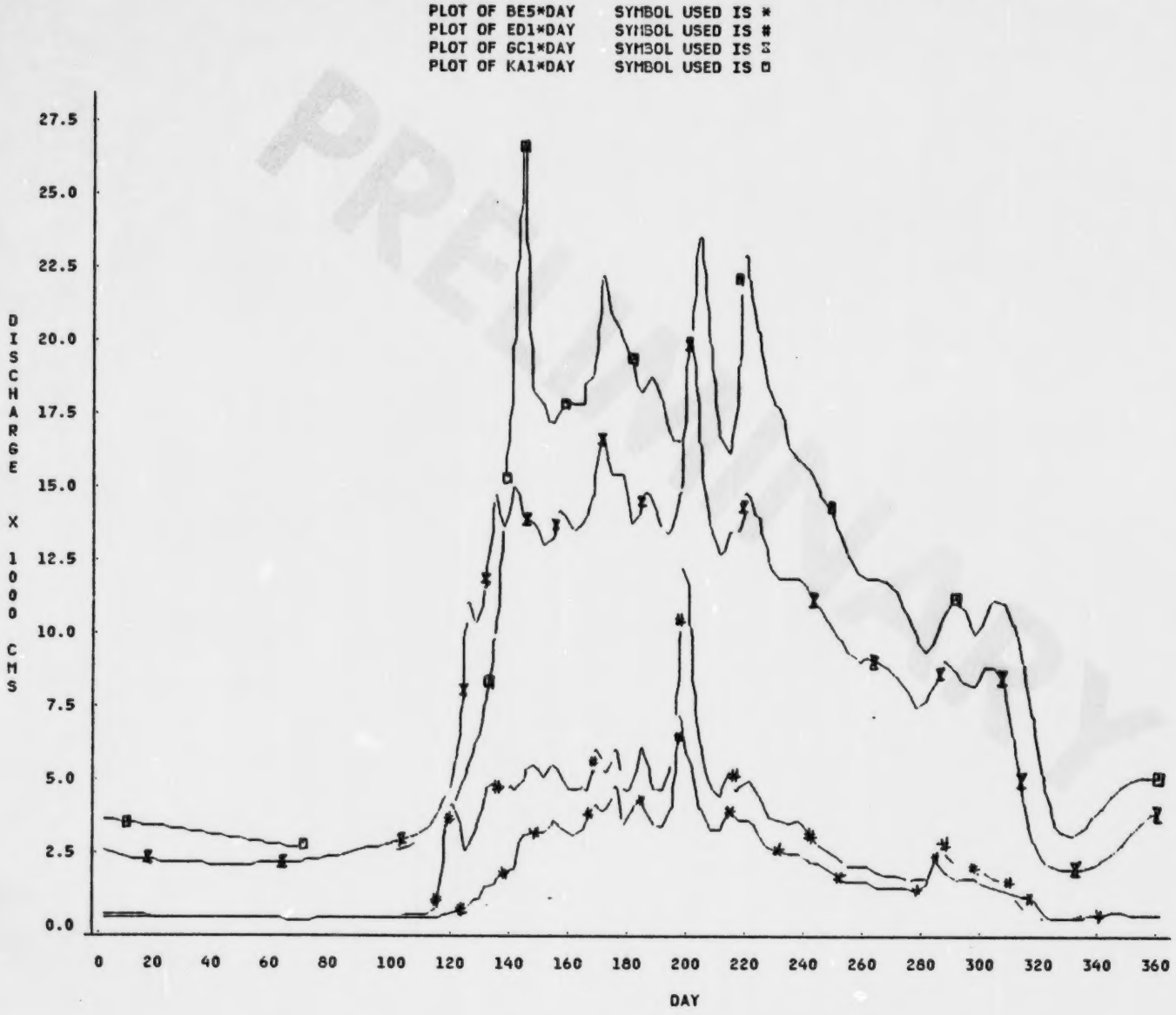
Beginning at Inuvik, where the ice forms about the second week of October, the Mackenzie River freezes southward. By the end of the second week of November, it is normally frozen over as far south as Fort Norman, and at Fort Simpson above the mouth of the Liard River by the end of the month.

Ice begins to form in the small bays along the northern shore of Great Slave Lake about 15 October, and navigation usually ceases shortly thereafter. The thickness of ice varies in different localities and from year to year, but it usually is 75 to 90 cm thick by 15 January, and reaches a maximum between 150 and 180 cm by about 1 March. As the ice thickens, pressure ridges, often 1.8 to 3 m high and sometimes more than 50 km in length are formed.

Freeze-up starts in both the Liard and Fort Nelson rivers during the latter half of October. It progresses downstream from Fort Nelson and Nelson Forks, reaching Fort Liard by the end of the month, and the mouth of the Liard River by the first week in November. The mouth of the Liard River is generally frozen before the Mackenzie River into which it flows.

Spring break-up in the Mackenzie system normally commences at Fort Nelson on the Fort Nelson River during the last week in April (Sherstone 1978). It moves downsteam to the confluence with the Liard

FIGURE 3-1. DAILY ANNUAL HYDROGRAPH FOR TYPICAL YEAR (1974) FOR LIARD RIVER AT SITE A (B.C.) AND FORT LIARD (NWT) AND MACKENZIE RIVER AT FORT SIMPSON (NWT) AND NORMAN WELLS (NWT)



River at Nelson Forks, and triggers the downstream Liard break-up. The break-up reaches the mouth of the Liard River, a short distance above Fort Simpson, during the first week of May. The break-up along the mainstem Mackenzie is normally complete as far as Fort Providence by the third week of May, and reaches Inuvik by the end of May.

Ice jamming occurs during spring break-up at numerous locations along the river (Sherstone 1978). Water levels back up 6+ m above open water high levels. Jamming at km 0 (mi 0) can drop water levels at the Fort Providence ferry crossing, km 64 (mi 40), that it hampers or cuts off ferry traffic. Water levels at Norman Wells frequently go 6 m above the Imperial Oil wharf and leave ice ridges up to 7.5 m high on the wharf after water levels recede (Renewable Resources Ltd 1978).

Ice jamming and ridging with water backup also occur frequently during the freeze-up period. Fort Providence experienced one in the fall of 1975 which prematurely cut off ferry traffic and backed water levels above the summer high water levels. Public Works Canada (1976) encountered massive ice layers and ice ridges at Sans Sault Rapids in January, February, and March of 1971 and again in March 1975. In March of both years, water levels were still about 30 cm above high open water season levels. In November 1974 ice jamming brought water levels up approximately 2.7 m at Norman Wells to cover the wharves; by January 1975, however, the water levels at Norman Wells had receded approximately 1.5 m. In November 1974 the ice jamming apparently extended down to the Ramparts (Renewable Resources Ltd 1978).

3.4 OBSTACLES TO NAVIGATION

The most critical areas for navigation on the Mackenzie River are as follows: (see Fig. 1-1).

1. Beaver Lake km 0 to 60 (mi 0 to 37)

This area includes the channel between Great Slave Lake and Beaver Lake as well as Beaver Lake itself. The connecting channel is wide and shallow with currents ranging to 4.8 km/h. Bottom material consists mainly of hard till. Beaver Lake is an area of little current and shallow water, restricting the navigable channel depth to approximately 1.5 m.

2. Providence Rapids km 61 (mi 38)

Providence Rapids, although swift running, are not turbulent. The strongest currents are to be found in the comparatively deep main channel where water depths are in the order of 4.6 to 7.6 m. However, the fast currents, averaging about 9.7 km/h, along with a twisting channel impede navigation.

3. Green Island Rapids km 298 (mi 185)

The main shipping channel, about 183 m in width, follows the south bank of the Mackenzie River closely from Berens Landing to the western end of Hanson Island where the channel is constricted to a width of approximately 92 m by a shoal area extending northward from the south bank. This narrow section, about 1 km in length, is intricate and passage is made more difficult by the current flowing at about 9.7 km/h.

4. Sans Sault Rapids km 1018 (mi 632)

The Sans Sault Rapids are considered the most difficult and dangerous section of the Mackenzie River to navigate. The rapids are formed by a rocky ledge that extends into midstream from the east bank. At high stages they are drowned out by the turbulent, swift-running river. At low stages the rapids are shallow and less turbulent with water depths in the order of 1.2 to 2.4 m, but contain numerous eddies with currents between 5.6 and 7.2 km/h.

A $3 million improvement program, designed to clear a channel through the rapids, was completed by the Department of Public Works at the Sans Sault Rapids by the fall of 1971. It presently provides a 2.1 m deep channel and after clean up operations approximately 2.4 m will be available. Maintenance dredging is undertaken by the Canada Department of Public Works.

5. The Ramparts Rapids and the Ramparts km 1087 (mi 675)

The Ramparts Rapids are formed by a series of limestone ledges that extend in a southeasterly direction from the northern bank of the Mackenzie River about 1.6 km below Spruce Island. At high stages of the river, the rapids are drowned out and present no serious navigational hazard. During periods of low water, towards the middle of September, a distinct drop forms over a distance of approximately 457 m through which the current flows at between 9.7 and 11.2 km/h. For about 1.6 km below the Ramparts Rapids the current maintains a speed of about 9.7 km/h, as the Mackenzie River approaches the Ramparts.

The Ramparts are entered at km 1087 (mi 675) between perpendicular limestone cliffs, 30 to 60 m in height. The entrance is about 400 m wide and very deep; consequently there is no increase of current, which averages about 4.8 km/h throughout the 11.2 km length of the Ramparts.

There are no serious obstacles to navigation in the Fort Nelson River during high water. The average gradient is 0.28 m/km and the current is moderate but barge pilots must be experienced as there are no navigational markers. However, during low water in August and September, the river is hazardous. The navigation channel is generally shallow, from 0.6 m to 2.4 m deep at the end of the barging season, and in places as narrow as 25 m. It also has some narrow sharp right angle bends.

The main deterrent to navigation in the Liard River is the swift current brought about by the steep gradient. This varies from 0.9 m/km between Hell Gate and Nelson Forks, 0.4 m/km between Nelson Forks and Fort Liard, and as high as 1.1 m/km in the Liard Rapids. The current correspondingly varies between a low of 4.8 km/h and as high as 13 to 19 km/h. This latter is achieved in the Liard Rapids during low water of 0.9 to 1.2 m at the end of August. This low water determines the end of the barging season on the lower Liard River. Even tugs which draw only 0.6 m of water when idling, such as those from Fort Nelson, cannot push a barge upstream over the rapids in less than 1.2 m because at full power their propellors are damaged by stones thrashed up from the river bed.

PRELIMINARY

SECTION 4.0 - TRANSPORTATION SYSTEMS

4.1 RIVER BASED - MACKENZIE RIVER

The Mackenzie valley water transportation system comprises the northern sector of the Mackenzie River watershed from the end of rail service at Hay River on Great Slave Lake to Tuktoyaktuk on the Arctic coast, a water navigation distance of some 1800 km. Both communities are important shore terminals and trans-shipment points for the bulk of cargo handled either along the Mackenzie valley or in the western Arctic.

Major communities along the Mackenzie River include Fort Simpson, pop. 937, Wrigley, pop. 236, Fort Norman, pop. 311, Norman Wells, pop. 378, Fort Good Hope, pop. 410, Arctic Red River, pop. 135, Inuvik, pop. 3354, Fort McPherson, pop. 851, Aklavik, pop. 849 and Tuktoyaktuk, pop. 748, with a total population for these communities of approximately 8209 (population estimates from 1976 federal census (Canadian Transport Commission 1978). River transportation to these communities is supplied by Northern Transportation Company Ltd.

Beginning in June, the ice-free season ranges from 180 days in the south to 100 days near Tuktoyaktuk. The first open water develops at the mouth of the Liard River about 5 May and that river is open after the 18th. On the Mackenzie River, open water develops in the upper section from Wrigley to Fort Providence during the last week of May, with the last ice at Fort Providence about 13 June. Ice breakup begins at Norman Wells between 15 and 20 May, Wrigley on 27 May, Fort Good Hope about 1 June, Inuvik by 6 June and Tuktoyaktuk by 1 July. The navigation season on the Mackenzie River lasts from mid-June until late October with average freeze-over occurring 12 October at Aklavik, 15 October at Tuktoyaktuk and 22 October at Inuvik. The upstream progression is steady, reaching Fort Good Hope on 8 November, Fort Norman by 14 November and Fort Simpson by the 27th.

The Mackenzie River is navigable along its entire length, although five sections may present navigational problems, especially at low water stages. These were described in detail in Section 3.4.

Water levels on the Mackenzie River dictate the barge draughts throughout the entire season of navigation. In general, a 1500 series barge owned by Northern Transportation Co. Ltd. (NTCL) is designed for a fully loaded draught of 1.8 m. Loading restrictions due to low water levels may reduce this capacity to 1.3 or 1.4 m draught. According to NTCL sources, the ideal load for a 1500 series barge, under optimum conditions on the Mackenzie River, is 1220 t and for the Beaufort Sea, 2180 t. Average tows may consist of a tug and up to nine barges.

After the high water of the early season recedes, it becomes necessary to break tows and relay barges through each of the problem stretches on the river. Relaying consists of towing the barges through the rapids in smaller numbers and reconstituting the full tow below the rapids. For example, an eight-barge tow might be relayed as two tows of four barges each. At the discretion of the master of the tug, long tows may be relayed through the Providence Rapids, making use of the mooring buoys at the west end of Beaver Lake and the barge tie-up facilities located at the south end of Mission Island. The same procedure may be necessary at the other rapids. The shipping channel through Green Island Rapids is well marked with aids defining the track. The Sans Sault Rapids are considered the most difficult and dangerous section of the Mackenzie River to navigate. At low water stages, the rapids are shallow and less turbulent, but contain numerous eddies. During the past few years, considerable blasting and dredging has taken place at Sans Sault. The Ramparts Rapids are formed by a series of limestone ledges. The rapids are submerged at high stages of the river while during periods of low water towards the middle of September, a distinct drop forms, through which the current flows at approximately 9 to 11 km/h.

Total cargo transported by all licenced operators in the Mackenzie River between Hay River and the delta from 1968 to 1977 is indicated in Table 4-1 and in Fig. 4-1. The volumes of cargo transported are strongly influenced by the amount of gas and oil exploration activity in the north (Swan Wooster Ltd 1972, Travacon Ltd 1973, Canadian Transport Commission 1978). Northern Transportation Company Ltd are responsible for more than 80 percent of all cargo shipped.

The Peel River, a tributary of the Mackenzie delta, lies partly in the Northwest Territories and partly in the Yukon Territory and has its headwaters in the Mackenzie Mountains, over 483 km from its junction with the Mackenzie River. The main settlements in this area are Fort McPherson and Aklavik. Fort McPherson is situated on the east bank of the Peel, about 44 km above the junction of the Peel and Mackenzie rivers. Aklavik is situated on the west bank of the Peel Channel, close upstream of the junction of the West Peel and Aklavik channels. Service is provided to both communities mainly by NTCL tugs and barges from Hay River and Inuvik, although one other licensee, Lindberg Transport Ltd., is authorized to provide service to the area.

4.2 RIVER BASED - LIARD AND FORT NELSON RIVERS

The Fort Nelson River is navigable from Fort Nelson for a distance of 165 km downstream to Nelson Forks, where it joins the Liard River. The Liard River is navigable from Hell Gate, 138 km above Nelson Forks, to Fort Simpson at the confluence of the Liard and Mackenzie Rivers, 420 km below Nelson Forks.

Navigation on the Fort Nelson and Liard rivers commences mid-May, as soon as the Liard River is clear of ice, and is terminated around the end of August by low water in the Fort Nelson River. The Fort Nelson River is clear of ice about one week before the Liard River. The first barge trip downstream from Fort Nelson usually starts between 10 and 20 May, when ice goes out of the Liard River. The stage of the rivers is fairly low at this time but there is enough water for navigation.

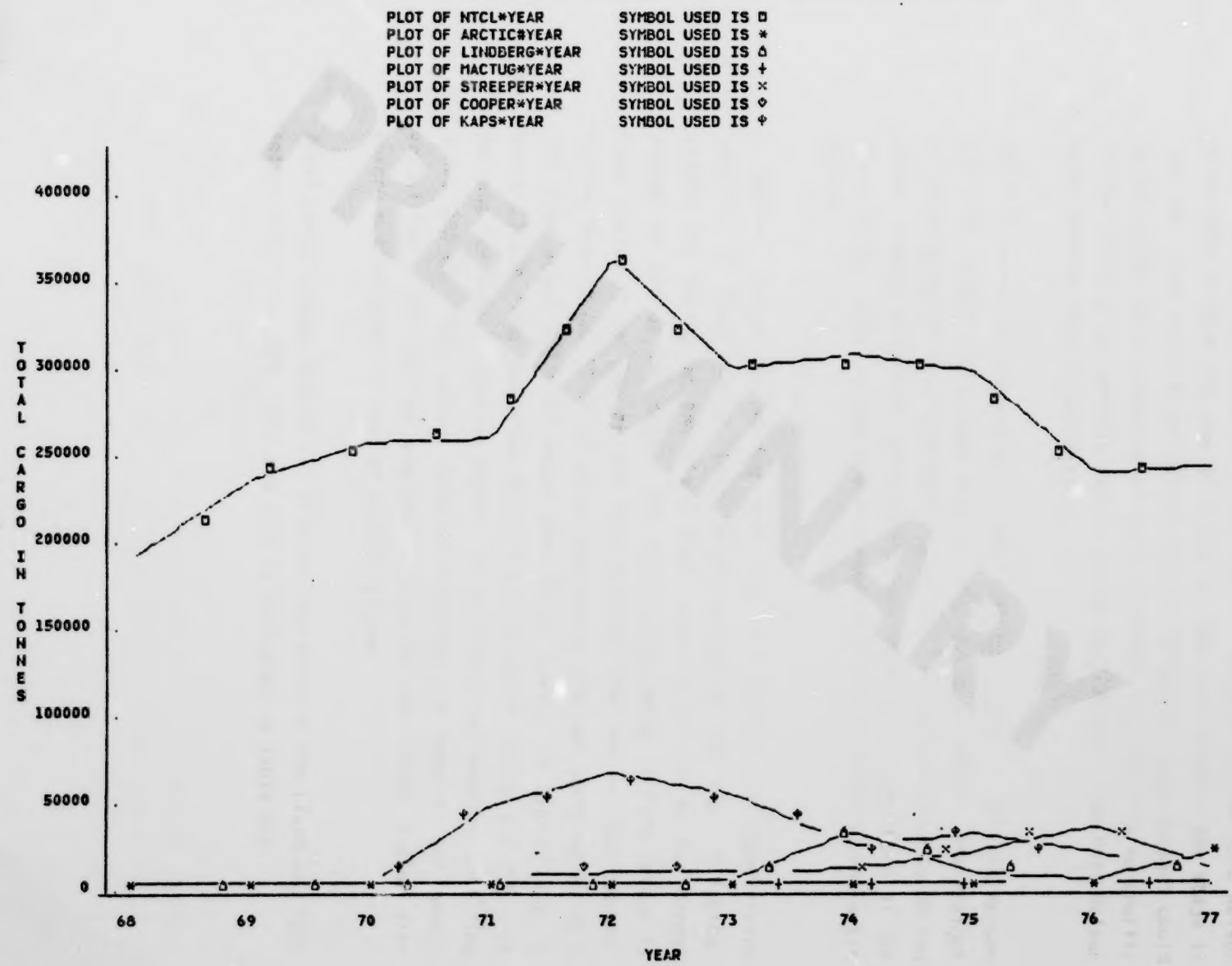
TABLE 4-1

TOTAL CARGO (TONNES) TRANSPORTED ON MACKENZIE RIVER, 1968 TO 1977

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Northern Transportation Company Ltd.	187 763	232 564	254 684	257 029	361 648	297 475	305 384	295 529	236 919	241 475
Arctic Transportation Ltd.	-	-	-	-	-	-	-	-	-	15 485
Lindberg Transport Ltd.	554	622	404	-	-	2 608	30 674	6 043	2 491	17 963
Mac Tug Ltd.	-	-	-	-	-	1 089	134	82	-	-
Streeper Bros. Marine Transport Ltd.	-	-	-	-	-	4 779	9 185	18 312	33 179	8 620
Cooper Barging Ltd.	-	-	-	4 114	6 789	7 272	4 896	5 114	2 446	3 878
Kaps Transport Ltd.	-	-	-	45 360	64 162	52 177	22 316	28 936	18 779	-
TOTALS	188 317	233 186	255 088	306 503	432 599	365 400	372 589	354 016	293 814	287 421

Data from Canadian Transport Commission (1978).

FIGURE 4-1
TOTAL CARGO (TONNES) TRANSPORTED BY BARGING COMPANIES ON MACKENZIE RIVER 1968-1977



PRELIMINARY

The barging season on the Liard River between South Nahanni and Fort Simpson ends most often between mid-August and mid-September, being determined by the stage of Liard Rapids. Barging on the Fort Nelson River ends at much the same time and for the same reason - the stage is too low. The Liard River between Nelson Forks and South Nahanni could be navigated until freeze-up early in November, but there is no traffic on the Liard after barging ceases on the Fort Nelson. The Fort Nelson River freezes over in mid-October.

The transportation companies operate freight barges on the Fort Nelson and Liard Rivers using tugs drawing only 0.6 m of water. The freight is moved by barge from Fort Nelson down the Fort Nelson River to Nelson Forks, thence to various settlements and landings on the shore of the Liard River. Some is even moved beyond Fort Simpson into the Mackenzie system.

A typical loaded tow moving down the Fort Nelson and Liard rivers consists of from one to four barges pushed by one tug. A typical loaded tow moving up the Liard River consists of one or two barges pushed by one or two tugs. The return trip empty to Fort Nelson is made typically by one or two tugs pushing from one to four barges. Barges draw about 23 cm of water when empty and can carry up to 91 t and draw about 1.2 m of water when fully loaded. A typical tug is about 12.2 m long and draws about 0.6 m of water idling and 0.9 m at maximum throttle in shallow water. It has two diesel engines totalling about 300 kW. Twin screws (counter-rotating) are required for maneuverability. Two smaller engines instead of one larger engine also ensure motive power in case of engine failure.

Total cargo transported by all licenced operators in the Liard and Fort Nelson rivers in 1976, 1977 and 1978 is indicated in Table 4-2.

TABLE 4-2

TOTAL CARGO (TONNES) TRANSPORTED ON LIARD AND FORT NELSON RIVERS

	1976	1977	1978
Cooper Barging Service Ltd.	2446	3652	5677
Streeper Bros. Marine Transport Ltd.	2948	982	-
TOTAL	5394	4634	5677

Data from Canadian Transport Commission (1978)

4.3 SHORE TERMINAL FACILITIES

Five carriers are presently licensed to transport cargo on the Mackenzie and provide the terminal facilities listed below. Various other companies including Kaps Transport Ltd and MacTug Ltd have been licensed at various times, but were not operating on the Liard or Mackenzie as of 1977.

1. Northern Transportation Company Limited (NTCL)

The single largest carrier is a federal crown corporation and handles all types of cargo. In addition to facilities at Tuktoyaktuk, NTCL has 0.65 ha of leased shore terminal facilities at Norman Wells, 137 m of wharves, a 84 m^2 mechanical repair shop, and accommodation for personnel and ancillary shore equipment; a 17 ha terminal at Inuvik, with a 372 m^2 garage, a 144 m wharf, a 1858 m^2 warehouse, operations, office and personnel accommodation, and ancillary shore equipment.

2. Arctic Transportation Ltd.

Engaged in the carriage of cargo in support of oil and gas exploration activities; has a 10 ha gravelled storage yard at Fort

Providence with camp accommodation 19 km away; and at Inuvik a 10 ha storage yard, camp and office accommodation, as well as a 46 m dock.

3. Lindberg Transport Ltd.

A carrier also principally engaged in petroleum exploration industry traffic; has 4 ha under long term lease, with 305 m of waterfront and a 186 m^2 warehouse at Fort Simpson and the use of 1.6 ha, a 372 m^2 warehouse and 91 m waterfront at Inuvik.

4. Streeper Bros. Marine Transport Ltd.

Also mainly engaged in support of the oil and gas exploration industry; has a 4.9 ha site for the storage of equipment at Fort Simpson.

5. Cooper Barging Service Ltd.

Operating a common carriage operation on the Liard and Fort Nelson rivers, does not have shore terminal facilities on the Mackenzie River.

Where carriers do not have their own shore terminal facilities, public and industrial wharves are used, and in areas where no docking facilities exist, freight is off-loaded over barge gangplanks to the beach. Some carriers, particularly NTCL, carry forklift trucks or maintain work barges equipped with unloading facilities for use in off-loading cargo at wharves and other points along the river where shoreside equipment is not available.

4.4 ALTERNATIVE TRANSPORTATION SYSTEMS

(a) Highways

The highway system in the Mackenzie basin can be classified into two principal types, namely all-weather roads and winter roads.

Access from the south is provided by the Mackenzie Highway which runs north from Alberta to within 16 km of the community of Wrigley. However, it is only open to the public to a point 80 km beyond Fort Simpson. The last 108 km are completed but have not been opened to the public as there are two river crossings within that stretch and ferries have not been provided. The bulk of highway traffic originates in Edmonton, Alberta, and terminates in Hay River, N.W.T.

The Mackenzie Highway is only open as far as Fort Simpson in the winter. Due to the reduction in oil and gas exploration in the late 1970's there was no requirement to build a winter road north from Fort Simpson down the river. Possible development of the oil fields at Norman Wells and the construction of an oil pipeline southwards will probably necessitate eventual extension of the MacKenzie Highway to Norman Wells. There presently is no direct highway link down the Mackenzie valley between Fort Simpson and the communities in the Mackenzie delta at any time of the year.

The Dempster Highway linking Dawson in the Yukon with Fort McPherson and Inuvik in the Mackenzie delta was opened in 1979. It is 671 km long and provides a year round link to the Alaska Highway and thence to western Canada through British Columbia.

The Liard Highway is under construction south from a point on the Mackenzie Highway south of Fort Simpson. It will eventually connect with the Alaska Highway north of Fort Nelson via the community of Fort Liard. There is no prediction yet as to when it

will be completed. A winter road is built every year from the Alaska Highway in British Columbia to Fort Liard to supply the community and oil and gas exploration operations in the area. It follows approximately the permanent road presently under construction.

The foregoing indicates that Fort Simpson and an 80 km stretch downstream along the Mackenzie River has year round highway access to the rest of Canada. So also do the communities of Fort McPherson and Inuvik in the delta. However, the communities in the 942 km of river valley between these points are dependent solely on river transportation or on air transport for all their supplies. The latter is expensive and impractical for bulk cargoes and is used mainly for supply of perishable commodities, apparel and light equipment (Travacon Ltd 1973). River transportation is limited to the open water navigation season of approximately 5 months which is dependent on the time of spring break-up, fall freeze-up, and the flow conditions and water levels in between.

A similar situation applies to the communities on the Fort Nelson and Liard rivers between Fort Nelson and Fort Simpson. They are heavily dependent on river transportation for the bulk of their supplies.

(b) Air

Air transport plays an important role in the Mackenzie basin transportation network, but this is inversely proportional to the availability of other transportation systems. Where a community is served by air, water and highway transport, scheduled aircraft services are used to move as little as 5 percent of all commodities which normally might be considered to be moveable by air. This increases substantially for some communities when there is no highway service and water is the only alternative. For example,

in such communities during 1970 approximately 55 percent of perishable foods were transported by air along with close to 43 percent of clothing and 20 percent of miscellaneous manufactures (Travacon Ltd 1973).

There are three principal types of air carriers operating within the Mackenzie basin. These can be classified as follows: 1) scheduled service carriers (who may also offer charter services); 2) air charter carriers; and 3) private carriers.

There are three scheduled carriers providing regular air service to communities in the Mackenzie basin. They are CP Air serving Fort Nelson, Pacific Western Airlines serving Fort Simpson, Inuvik, Norman Wells and Hay River, and Northward Airlines serving Fort Good Hope, Fort McPherson, Fort Norman, Fort Simpson, Inuvik, Norman Wells and Tuktoyaktuk. In addition there are 14 charter carriers operating in the Mackenzie basin, and a number of private carriers devoted almost exclusively to oil and gas exploration activities.

Pacific Western is by far the largest of the carriers operating in the area and has the most extensive route pattern and highest frequency of service. Basically it links Calgary and Edmonton to the larger Mackenzie valley centres with the following frequencies:

Inuvik	15 flights per week
Hay River	12 flights per week
Norman Wells	3 flights per week
Fort Simpson	2 flights per week

In addition PWA provides links between Inuvik and Fort Simpson and Norman Wells. The service provided by Northward Airlines is strictly intercommunity within the Northwest Territories. PWA and

Northward Airlines both provide charter services mainly to service oil rigs and other exploration activities. The smaller charter carriers provide an essential intercommunity service and handle the major portion of the high value, low bulk and perishable goods business between these communities.

A third significant component of the Mackenzie valley air transport system is that involving the use of corporate aircraft. This primarily serves the oil and gas industry moving personnel, equipment and supplies to and from the drill rigs and base sites. It is estimated that more than 725 000 kg of freight was moved from Edmonton to the Mackenzie delta by corporate aircraft in 1970 (Travacon Ltd 1973).

Some communities in the Mackenzie valley are served by more than two forms of transportation. Of the principal settlements only three, Hay River, Fort Simpson and Inuvik are regularly serviced by three major modes i.e. year round truck service, water and scheduled airline. A number of other principal communities such as Norman Wells have relatively high frequency service by water and scheduled airline. Table 4-3 summarizes the type of transportation service available to each of the principal communities. While air transportation provides an essential service to the communities, particularly in the winter, it cannot be utilized on a long-term basis to transport bulk supplies because of cost and capacity.

TABLE 4-3

NORTHWEST TERRITORIES TRANSPORTATION SERVICE
FACILITIES AVAILABLE TO SELECTED COMMUNITIES

Community	Rail	All Weather Road	Winter Road	Water	Scheduled Air Service
Hay River	X	X		X	X
Fort Providence		X		X	
Fort Simpson		X		X	X
Wrigley			X	X	X
Fort Norman			X	X	X
Norman Wells			X	X	X
Fort Good Hope			X	X	X
Arctic Red River		X	X	X	X
Fort McPherson		X		X	X
Aklavik			X	X	X
Inuvik		X		X	X
Tuktoyaktuk			X	X	X

PRELIMINARY

SECTION 5.0 - IMPACTS ON RIVER NAVIGATION

5.1 ICE CONDITIONS

As indicated in Section 2.0, a more detailed evaluation of changes in the ice and break-up conditions in the Liard and Mackenzie rivers under a regulated river regime will be made by 1981. A revised assessment of potential impacts of changes in break-up on river navigation could be made at that time.

Comparison of times of ice break-up in the Peace River near the town of Peace River, Alberta before and after regulation by the Portage Mountain development is given in Table 5-1. These data suggest that under regulated conditions the date of annual ice break-up varies more than under natural conditions. However, the median date of break-up is almost the same in both cases, and there is no statistically significant difference between the two sets of break-up dates (Mann-Whitney $U=43$, $p>0.05$). The data indicate that the dates of ice cover formation in late fall are strongly affected by upstream regulation and are both delayed and subject to more variation. The median date of ice cover formation at Peace River has been delayed by nearly 3 weeks under regulated conditions, and there is a strongly significant difference between the two sets of dates (Mann-Whitney $U=88$, $p<0.01$).

Spring break-up in the lower Liard appears to be a function of river discharge, ice volumes and the amounts of thermal erosion preceeding the actual break-up. Based upon mathematical modelling Lasalle Hydraulic Laboratory Ltd (1980) have tentatively predicted a 2-week delay in spring break-up in the Liard below Site A. This would result primarily from larger volumes of ice which have to be cleared. Water levels behind the larger ice jams might be 2 to 3 m higher than at present and this might result in larger amounts of log debris entering the river, at least for the first 10 years following impoundment and

TABLE 5-1

COMPARISON OF ICE BREAK-UP AND COVER DATES*1
AT PEACE RIVER, ALBERTA (WATER SURVEY GAUGE 07HA001)*2
BEFORE AND AFTER REGULATION BY THE PORTAGE MOUNTAIN DEVELOPMENT

Before Regulation			After Regulation		
Year	Break-up	Ice Cover	Year	Break-up	Ice Cover
1958	April 15	November 8	1968	-	November 7
1959	April 19	November 13	1969	April 22	November 17
1960	April 27	November 8	1970	April 17	November 24
1961	April 22	October 24	1971	April 22	November 28
1962	April 19	November 14	1972	April 29	December 3
1963	May 1	November 4	1973	April 16	November 6
1964	April 26	November 8	1974	April 27	January 6
1965	April 22	November 5	1975	April 28	December 1
1966	April 15	November 1	1976	April 16	December 6
1967	May 6	November 9	1977	April 1	December 4
1968	April 24	-	1978	April 18	-
Earliest	April 15	November 1		April 1	November 6
Latest	May 6	November 14		April 29	January 6
Median	April 22	November 9		April 20	November 29

*1 As indicated by icing conditions recorded at the WSC water level gauge.

*2 Data from Water Survey of Canada (1979).

hydroelectric operation. The impact on Liard River navigation is thus likely to be a delay of about 1 to 2 weeks in commencement, but observations on the lower Peace River would suggest that this period is likely to be highly variable. Barges using the lower Liard originate from Fort Nelson and use the Fort Nelson River. This would not be generally affected by Liard River hydroelectric development, although high water levels, increased ice volumes and larger ice jams may be apparent at the Fort Nelson-Liard River confluence.

The date of commencement of navigation on the Mackenzie River is dependent upon the progress of break-up in the upper reaches. Break-up in the section between Fort Simpson and Fort Providence (i.e. upstream of the Liard-Mackenzie confluence) is normally a few days later than in the lower reaches (Mackay 1963). This section thus essentially controls navigation on the Mackenzie since most NTCL barges are overwintered at Hay River on the Great Slave Lake. Most barges thus leave Hay River after June 1 (W.B. Hunter, Northern Transportation Company Ltd., personal communication), whereas the Mackenzie River just upstream of Fort Simpson is normally clear of ice at a date between May 16 and May 31 (Allen 1977). A 1-week delay in break-up in the Mackenzie River has been tentatively predicted on the basis of mathematical modelling (Lasalle Hydraulic Laboratory 1980). This would mean that break-up would occur between the third week in May and the first week in June, and thus could in some years cause a few days delay in commencement of navigation below Fort Simpson.

The major determinant of navigation on the lower Liard River in the late fall months is low stage. However, freeze-over could be the determining factor in those reaches where depth is adequate e.g. between Nelson Forks and the South Nahanni confluence. Based upon comparisons with the Portage Mountain Dam on the Peace River, it can be anticipated that turbine releases to the downstream river will delay freeze-over by at least 3 weeks (Table 5-1). However, barges using this section would have to come from, and return to, Fort Nelson via the Fort Nelson River because of low water stages in the Liard Rapids.

Navigation in the Fort Nelson River is usually not practical beyond the middle of September because of low water and hence freeze-over changes in the Liard River would be of little practical significance to navigation.

A similar situation would be expected to exist in the upper Mackenzie. Although freeze-over would be delayed, the problem of low stage in sections such as the Providence and Green Island rapids (which are upstream of the Liard confluence) would prevent any benefits to navigation being realized by prolonged open water downstream of Fort Simpson.

5.2 LOW WATER CONDITIONS

Comparisons between calculated regulated flows and SIMPAK simulated regulated flows for Scheme 2 for the summer and fall of the years 1973 through 1977 are given in Table 5-2 for the Mackenzie River at Norman Wells and in Table 5-3 for the Liard at Fort Liard. Because the SIMPAK simulation assumed a constant turbine release (Hydroelectric Generation Projects Division, B.C. Hydro 1980) whereas the releases assumed in this study mimicked the real-life situation and therefore rose or declined throughout any given month (Appendix A), the differences between the two sets or flows are highest at the beginning and end of each month. Calculated flows are statistically significantly different from SIMPAK simulated flows (as determined by testing Ho: difference = 0) in many cases, indicating that the calculated flows are higher or lower than the simulated flows throughout the major portion of the month. The mean differences in all these cases are very small however, and often less than 2 to 4 percent (Tables 5-2 and 5-3). The mean difference in flows is less than 2 percent in 26 out of 30 monthly comparisons for Norman Wells and less than 4 percent in 21 out of 30 monthly comparisons for Fort Liard. Inspection of the larger differences showed that they occured in months with erratic flows, probably due to local rainstorms. Under such conditions SIMPAK routing would provide better estimates of regulated flows than the simple differencing used in this study. Inspection of the predicted water

TABLE 5-2

COMPARISON OF REGULATED DAILY FLOWS (m^3/s) (SCHEME 2) IN THE MACKENZIE RIVER AT NORMAN WELLS AS COMPUTED IN THIS STUDY AND BY THE SIMPAK MODEL*1

Year	Month	Mean Daily Flow this Study	Mean Daily Flow SIMPAK	Difference*2 Min.	Difference*2 Mean	Difference*2 Max.	Mean Difference (%)	t Value*3	p
1973	June	17010	16844	-756	125	1173	0.9	1.2	0.23
	July	13688	13930	-770	-137	198	-0.9	-2.9	0.01
	August	12360	12148	-252	207	657	1.7	4.1	0.00
	September	11942	12039	-666	-62	403	-0.5	-1.0	0.30
	October	9021	9170	-447	-111	111	-1.1	-3.8	0.00
	November	5636	5591	-52	93	267	1.9	5.9	0.00
1974	June	16605	16563	-691	18	679	0.1	0.3	0.77
	July	15430	15491	-1626	40	1347	0.6	0.4	0.72
	August	17088	16874	-928	236	1729	1.6	1.4	0.18
	September	12539	12772	-585	-168	236	-1.1	-3.4	0.00
	October	10411	10285	-279	105	566	1.1	1.9	0.07
	November	7009	7146	-440	-47	221	0.2	-1.3	0.20
1975	June	17415	17136	-407	350	1163	2.0	4.7	0.00
	July	15108	15449	-3031	-410	203	-2.1	-3.0	0.00
	August	12977	12819	-291	195	840	1.5	2.4	0.02
	September	10364	10556	-482	-157	101	-1.4	-4.8	0.00
	October	9221	9325	-211	-74	37	-0.8	-6.4	0.00
	November	4788	4767	-48	68	226	1.5	5.1	0.00
1976	June	15495	15382	-970	142	1143	1.0	1.5	0.15
	July	17479	17103	-792	327	1534	2.1	2.2	0.04
	August	15331	15444	-753	-105	356	-0.6	-1.9	0.07
	September	12721	12962	-519	-142	13	-1.1	-5.3	0.00
	October	9596	9716	-278	-88	23	-0.9	-5.7	0.00
	November	6563	6569	-102	56	304	1.2	3.2	0.00
1977	June	18413	18424	-760	24	1032	0.1	0.2	0.83
	July	14035	14237	-1276	-163	578	-0.9	-1.6	0.12
	August	12857	13449	-1153	-534	165	-3.8	-7.4	0.00
	September	10316	10436	-407	-124	220	-1.2	3.3	0.00
	October	8831	8940	-428	-79	137	-0.8	-2.8	0.01
	November	5133	5128	-123	62	325	1.8	2.9	0.01

*1 Hydroelectric Generation Projects Division, B.C. Hydro (1980).

*2 Calculated regulated flow - SIMPAK computed flow.

*3 Testing H_o: mean difference between calculated and computed flows = 0.

TABLE 5-3

COMPARISON OF REGULATED DAILY FLOWS (m^3/s) (SCHEME 2) IN THE LIARD RIVER AT FORT LIARD AS COMPUTED IN THIS STUDY AND BY THE SIMPAK MODEL*1

Year	Month	Mean Daily Flow this Study	Mean Daily Flow SIMPAK	Difference*2 Min.	Mean	Max.	Mean Difference (%)	t Value*3	P
1973	June	3774	3774	-527	6	625	2.2	0.1	0.09
	July	2467	2507	-233	5	244	0.8	0.2	0.21
	August	2277	2144	-279	144	850	8.3	2.5	0.02
	September	2387	2438	-449	-60	393	-1.5	-1.2	0.23
	October	1367	1411	-182	-27	125	-2.0	-1.7	0.10
	November	1329	1278	-78	49	248	4.1	2.6	0.02
1974	June	2673	2678	-264	-4	304	0.3	-0.1	0.91
	July	3212	3166	-2173	45	567	6.7	0.4	0.67
	August	3449	3370	-1040	79	1797	9.8	0.5	0.62
	September	2176	2213	-446	-23	396	0.8	-0.5	0.61
	October	2015	1953	-391	45	626	4.0	0.9	0.38
	November	1174	1194	-443	-12	154	-0.1	-0.5	0.64
1975	June	3196	3090	-2984	61	895	9.0	0.4	0.70
	July	2516	2716	-704	-32	287	0.7	-0.7	0.48
	August	2895	2788	-437	74	695	2.3	1.1	0.28
	September	1673	1770	-341	-80	363	-3.0	-2.0	0.06
	October	1304	1359	-223	-45	85	-3.0	-2.5	0.02
	November	1230	1198	-135	30	236	2.6	1.8	0.08
1976	June	4830	4764	-674	21	387	0.7	0.4	0.68
	July	5185	4932	-660	205	1392	6.5	1.5	0.16
	August	5408	5453	-608	-27	385	-0.5	-0.6	0.54
	September	3095	3126	-194	7	448	0.9	0.3	0.79
	October	1681	1743	-470	-64	122	-3.4	-2.8	0.01
	November	1509	1477	-124	32	276	2.8	1.7	0.09
1977	June	5775	5685	-559	-13	513	-1.6	-0.2	0.82
	July	3035	3257	-1348	-263	416	-4.3	-2.4	0.02
	August	2766	3229	-1130	-448	79	-12.3	-6.1	0.00
	September	1929	2006	-573	-54	355	-1.5	-1.0	0.34
	October	1556	1601	-483	-27	154	-1.1	-1.1	0.29
	November	1188	1157	-197	34	328	3.7	1.3	0.19

*1 Hydroelectric Generation Projects Division, B.C. Hydro (1980).

*2 Calculated regulated flow - SIMPAK computed flow.

*3 Testing H_0: mean difference between calculated and computed flows = 0.

PRELIMINARY

levels showed that critically low levels seldom occurred in periods when flows were erractic. It was concluded that simple calculated regulated flows were adequate for predicting water levels under regulated and filling conditions. The absence of major lakes in the Liard system is expected to result in SIMPAK simulation of filling conditions providing flow estimates very close to those used in this study. Appendix B presents an example of daily stage predictions under regulated and filling conditions, compared to non-regulated conditions.

(a) Mackenzie River

Table 5-4 summarizes the estimated dates of navigation termination at the San Sault Rapids, for the natural (non-regulated) condition, for the reservior filling period and for regulation under Schemes 2 and 8 respectively. Fig. 5-1 presents probability curves derived from the same data and Table 5-5 presents estimates of the 10, 25, 50, 75 and 90 percent probabilities of critically low water levels being reached by certain dates. For the average cases (50 percent probability) there would be virtually no difference between natural and Scheme 2 regulated conditions, a 7-day extension under Scheme 8 regulation, and reservoir filling would reduce the navigation season by 14 days (Scheme 2) or 5 days (Scheme 8) respectively.

One of the most important effects of river regulation on water depths at points such as San Sault Rapids is to increase the annual variability in daily depth measurements. The effect is more marked with a development such as Scheme 2 which has a large amount of regulating capacity. Thus, although the average effect on navigation of the regulated Mackenzie River is the same as the non-regulated river, there is a 10 percent probability that regulation could either extend the navigation period through San Sault by 6 days or reduce it by 5 days (Table 5-5, Fig. 5-1). Scheme 8 could extend the navigation period by 5 to 10 days.

TABLE 5-4

COMPARISON OF LENGTHS OF NAVIGATION SEASON FOR LOADED BARGES
IN MACKENZIE RIVER AT SAM SAULT RAPIDS UNDER NATURAL AND REGULATED CONDITIONS
FOR SAMPLE 10-YEAR PERIOD

Year	Non-regulated		Reservoir Filling (Predicted)				Reservoir Operation (Predicted)			
			Scheme 2		Scheme 8		Scheme 2		Scheme 8	
	Water too Low for Navigation Date	Navig. Season Days[a1]	Water too Low for Navigation Date	Navig. Season Days[a1]	Water too Low for Navigation Date	Navig. Season Days[a1]	Water too Low for Navigation Date	Navig. Season Days[a1]	Water too Low for Navigation Date	Navig. Season Days[a1]
1968	August 13	74	July 27	57	August 14	75	July 28	58	August 16	77
1969	July 30	60	July 26	56	August 2	63	July 28	58	August 7	68
1970	July 29	59	July 3	33	July 26	56	July 26	56	July 31	62
1971	July 31	61	July 27	57	July 29	59	July 30	60	August 7	68
1972	September 1	93	August 28	89	August 29	90	September 2	94	September 5	97
1973	September 21	113	July 25	55	August 12	73	September 21	113	September 27	120
1974	September 15	107	September 9	101	September 13	105	September 28	119	October 1	123
1975	August 26	87	August 18	79	August 20	81	August 31	92	September 2	94
1976	September 20	112	September 15	107	September 18	110	September 21	113	September 29	121
1977	August 24	85	August 12	73	August 22	83	August 31	92	September 4	96
Minimum	July 29	59	July 3	33	July 26	56	July 26	56	July 31	62
Maximum	September 21	113	September 15	107	September 18	110	September 28	119	September 29	121
Median	August 25	86	July 30	60	August 17	78	August 31	92	September 3	95

[a1] Assuming navigation commences 1 June.

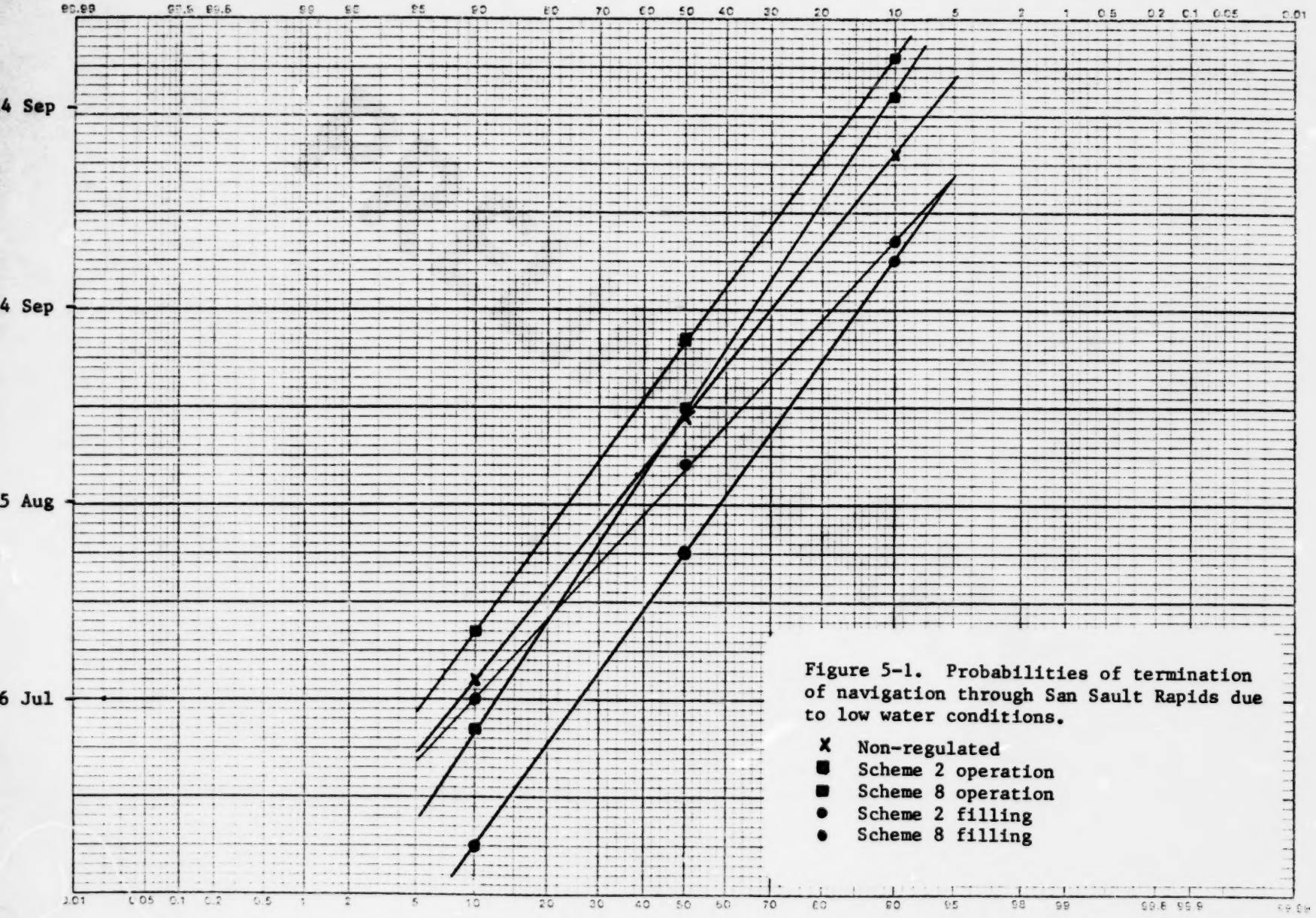


Figure 5-1. Probabilities of termination of navigation through San Sault Rapids due to low water conditions.

- Non-regulated
- Scheme 2 operation
- Scheme 8 operation
- Scheme 2 filling
- Scheme 8 filling

TABLE 5-6

COMPARISON OF LENGTHS OF NAVIGATION SEASON
IN MACKENZIE RIVER AT THE RAMPARTS RAPIDS UNDER NATURAL AND REGULATED CONDITIONS
FOR SAMPLE 10-YEAR PERIOD

Year	Non-regulated		Reservoir Filling (Predicted)				Reservoir Operation (Predicted)			
			Scheme 2		Scheme 8		Scheme 2		Scheme 8	
	Water too Low for Navigation Date	Navig. Season Days*1	Water too Low for Navigation Date	Navig. Season Days*1	Water too Low for Navigation Date	Navig. Season Days*1	Water too Low for Navigation Date	Navig. Season Days*1	Water too Low for Navigation Date	Navig. Season Days*1
1968	November 10	163	October 25	147	November 5	158	November 16	169	November 17	170
1969	November 6	159	November 1	154	November 5	158	November 10	163	November 12	165
1970	November 5	158	October 21	143	November 3	156	November 9	162	November 6	159
1971	November 7*2	160*2	November 6	159	November 6*2	159	November 10*2	163*2	November 9	162
1972	November 7	160	November 3	156	November 6	159	November 9	162	November 10	163
1973	November 10	163	November 9	162	November 9	162	November 13	166	November 13	166
1974	November 6	159	November 15	168	November 6	159	November 18	171	November 7	160
1975	November 4	157	November 2	155	November 4	157	November 7	160	November 7	160
1976	November 15	168	November 14	167	November 15	168	November 18	171	November 18	171
1977	November 9	162	November 7	160	November 8	161	November 13	166	November 12	165
Minimum	November 4	157	October 21	143	November 3	156	November 7	160	November 6	159
Maximum	November 15	168	November 15	168	November 15	168	November 18	171	November 18	171
Median	November 7	160	November 5	158	November 6	159	November 12	165	November 11	164

*1 Assuming navigation commences 1 June.

*2 River frozen over by October 28.

TABLE 5-5

PROBABLE DATES (EQUAL TO OR EARLIER THAN) OF
NAVIGATION TERMINATION FOR LOADED BARGES DUE TO LOW WATER IN THE
MACKENZIE RIVER AT SAN SAULT RAPIDS

Probability Percent	Non-Regulated	Reservoir Filling		Reservoir Operation	
		Scheme 2	Scheme 8	Scheme 2	Scheme 8
90	September 20	September 9	September 11	September 26	September 30
75	September 7	August 25	August 31	September 11	September 16
50	August 24	August 10	August 19	August 25	September 1
25	August 10	July 25	August 6	August 7	August 16
10	July 28	July 11	July 26	July 23	August 2

The absence of any marked effects of Liard River regulation on critical water depths in the San Sault Rapids would be due to a coincidence of declining river levels and rising turbine releases from the hydroelectric scheme. Long-term average river flows in the Mackenzie in late August and early September under natural and under Scheme 2 regulation are similar (Hydroelectric Design Division 1979). If turbine releases during this period were to differ markedly from the target flows, then navigational periods through San Saults might be correspondingly shortened or lengthened.

Similar analyses are presented for the Ramparts Rapids in Tables 5-6 and 5-7 and Fig. 5-2 respectively. Due to a more contained river channel and corresponding greater depths, critical low water levels at Ramparts Rapids typically occur much later in the season than at San Sault. This corresponds to the time of year when predicted turbine releases from the Liard dams would slightly exceed natural Liard River flows. The result is that

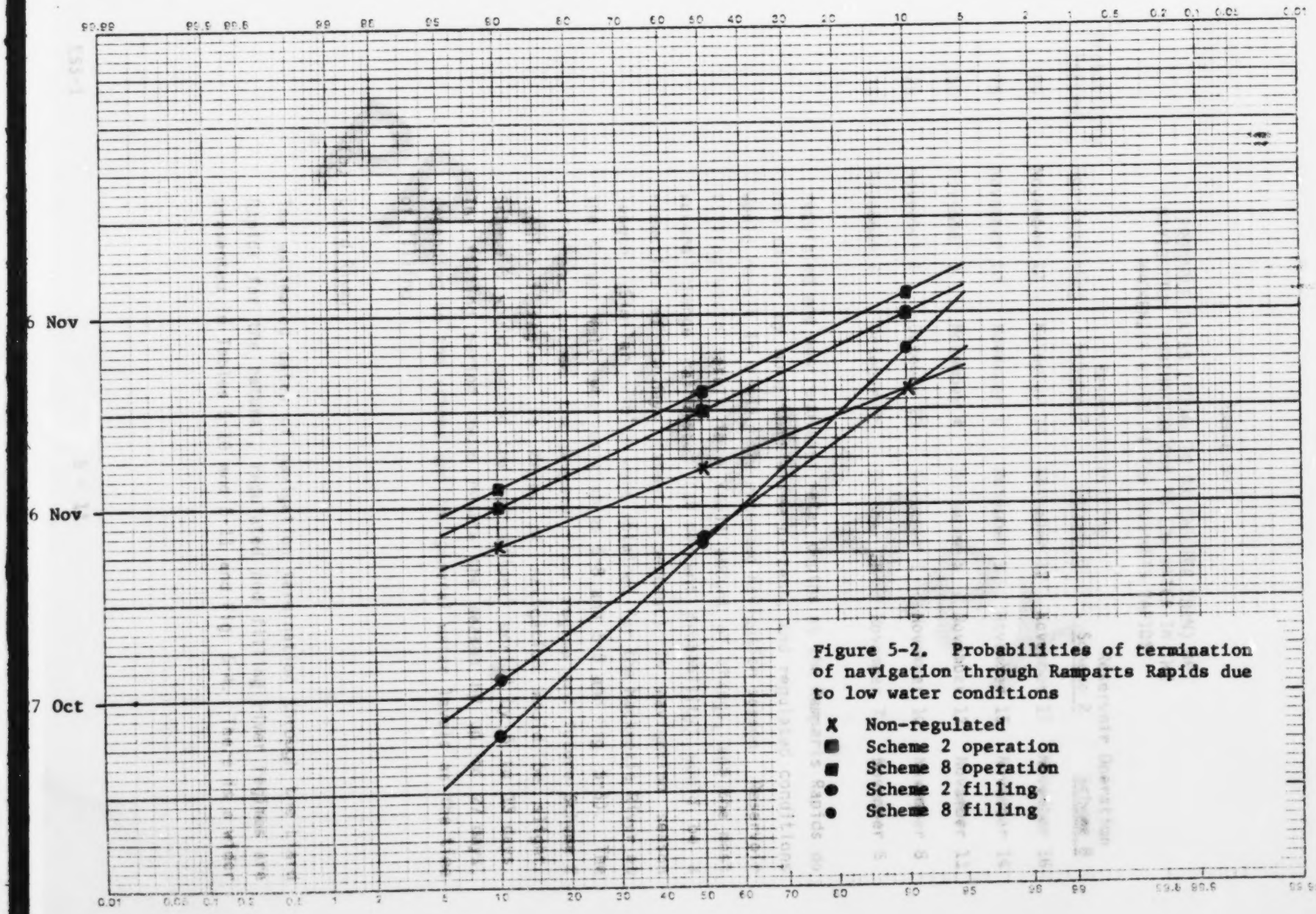


Figure 5-2. Probabilities of termination of navigation through Ramparts Rapids due to low water conditions

- Non-regulated
- Scheme 2 operation
- Scheme 8 operation
- Scheme 2 filling
- Scheme 8 filling

TABLE 5-7

PROBABLE DATES (EQUAL TO OR EARLIER THAN) OF NAVIGATION TERMINATION DUE TO LOW WATER IN THE MACKENZIE RIVER AT THE RAMPARTS RAPIDS

Probability Percent	Non-Regulated	Reservoir Filling		Reservoir Operation	
		Scheme 2	Scheme 8	Scheme 2	Scheme 8
90	November 12	November 14	November 12	November 17	November 16
75	November 10	November 9	November 9	November 15	November 14
50	November 8	November 4	November 5	November 12	November 11
25	November 6	October 29	November 1	November 10	November 8
10	November 4	October 25	October 28	November 7	November 6

regulated and non-regulated water depths at the Ramparts Rapids do not differ by more than a few percent, and regulated conditions would result in a slightly extended navigation season. Reservoir filling would result in a small amount of change, and the most severe change calculated (10 percent probability) would be a reduction of 10 days (about 8 percent) in navigation season length. Similar results were obtained for the Mackenzie River at the Norman Wells wharves (Tables 5-8 and 5-9 and Fig. 5-3). The difference between the present river regime and future Scheme 2 regulated regimes in terms of navigation would be slight. Scheme 8 would extend the navigational period by 5 to 13 days. The filling period could reduce the season by up to 27 days, depending on the scheme and the general water levels as the time of filling.

(b) Liard River

The estimated dates of navigation termination through the Liard Rapids for the natural, regulated and filling river regimes are presented in Tables 5-10 and 5-11 and Fig. 5-4. There is a wider

TABLE 5-8

COMPARISON OF LENGTHS OF NAVIGATION SEASON
IN MACKENZIE RIVER AT NORMAN WELLS WHARVES UNDER NATURAL AND REGULATED CONDITIONS
FOR SAMPLE 10-YEAR PERIOD

Year	Non-regulated		Reservoir Filling (Predicted)				Reservoir Operation (Predicted)			
			Scheme 2		Scheme 8		Scheme 2		Scheme 8	
	Water too Low for Navigation Date	Navig. Season Days[A1]	Water too Low for Navigation Date	Navig. Season Days[A1]	Water too Low for Navigation Date	Navig. Season Days[A1]	Water too Low for Navigation Date	Navig. Season Days[A1]	Water too Low for Navigation Date	Navig. Season Days[A1]
1968	October 12	134	September 17	109	October 7	129	October 15	137	October 31	153
1969	October 17	139	September 22	114	October 7	129	October 17	139	October 26	148
1970	October 14	136	September 10	102	September 18	110	October 14	136	October 18	140
1971	October 7	129	September 16	108	October 3	125	October 9	131	October 23	145
1972	October 17	139	October 4	126	October 12	134	October 18	140	October 28	150
1973	October 22	144	October 18	140	October 20	142	October 24	146	November 2	155
1974	November 12	165	Novemver 10	163	November 11	164	November 12	165	November 13	166
1975	October 26	148	October 21	143	October 24	146	October 28	150	October 30	152
1976	November 6	159	October 28	150	November 6	159	November 8	161	November 10	163
1977	October 24	146	October 10	132	October 22	144	October 27	149	November 2	155
Minimum	October 7	129	September 10	102	September 18	110	October 9	131	October 18	140
Maximum	November 12	165	November 10	163	November 11	164	November 12	165	November 13	166
Median	October 20	142	October 7	129	October 16	138	October 21	143	October 30	152

[A1] Assuming navigation commences 1 June.

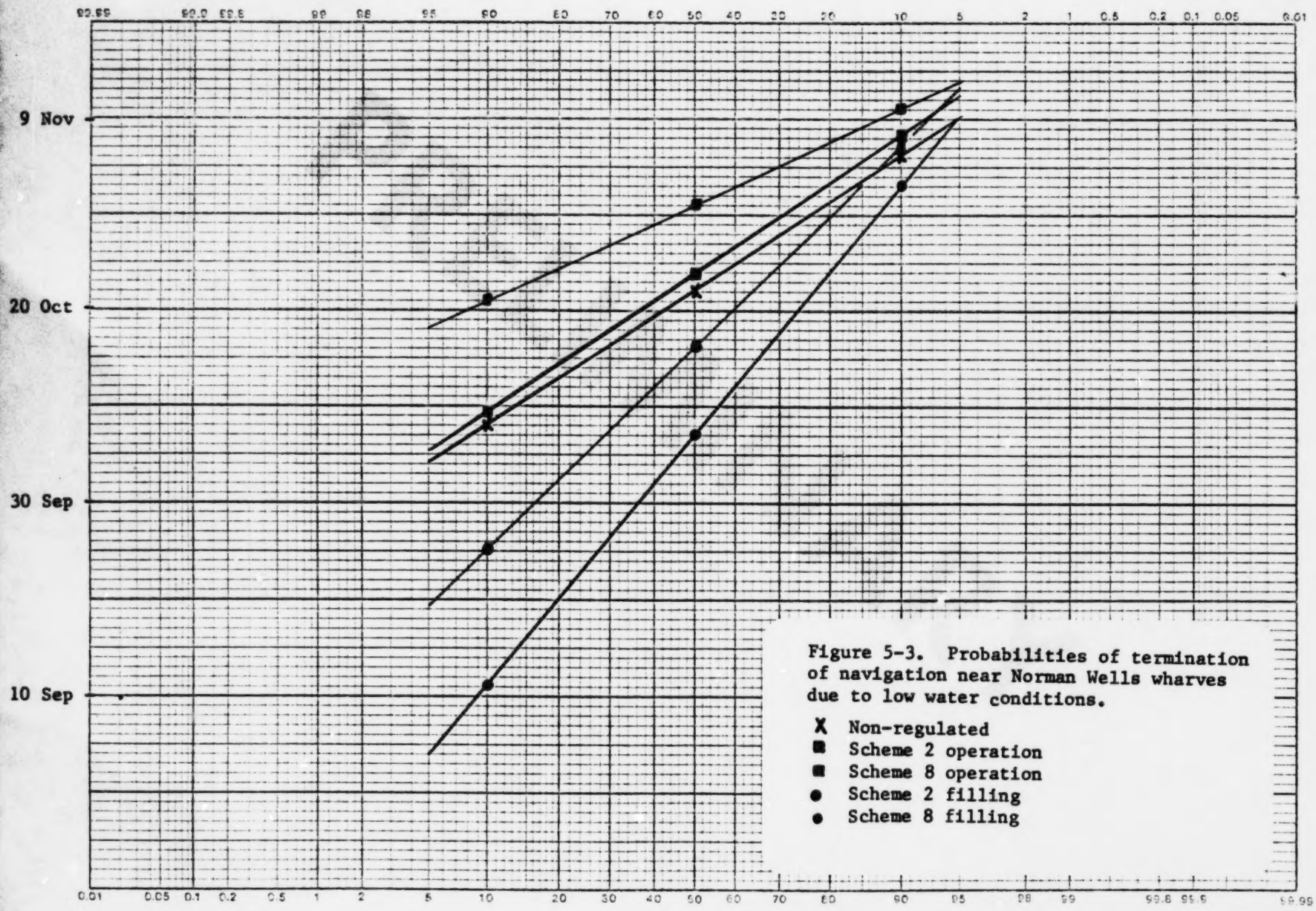


Figure 5-3. Probabilities of termination of navigation near Norman Wells wharves due to low water conditions.

- X Non-regulated
- ■ Scheme 2 operation
- ■ Scheme 8 operation
- ● Scheme 2 filling
- ● Scheme 8 filling

TABLE 5-9

PROBABLE DATES (EQUAL TO OR EARLIER THAN) OF NAVIGATION TERMINATION DUE TO LOW WATER IN THE MACKENZIE RIVER AT THE NORMAN WELLS WHARVES

Probability Percent	Non-Regulated	Reservoir Filling Scheme 2	Reservoir Filling Scheme 8	Reservoir Operation Scheme 2	Reservoir Operation Scheme 8
90	November 5	November 2	November 6	November 7	November 10
75	October 29	October 20	October 27	October 21	November 5
50	October 22	October 7	October 16	October 23	October 31
25	October 14	September 23	October 5	October 16	October 25
10	October 8	September 11	September 25	October 9	October 21

range of variation between natural and regulated conditions in the lower Liard River than in the Mackenzie due to the much smaller number of tributaries entering the river between Site A and Fort Simpson and the corresponding lack of buffering effect of inflowing water.

Scheme 2 river regulation would at times cause a substantial reduction in the length of the season in which the Liard Rapids could be negotiated. Over the long-term, there would be 1 year in 10 when the season would be terminated in early July, as opposed to early August under natural conditions. In the majority of years there would be little difference in the navigation period, and in some years (2 or 3 out of every 10) the navigational period could be extended occasionally to freeze-up. Scheme 8 would always extend the navigational period through the Liard Rapids (Table 5-11).

Reservoir filling would always shorten the period of navigation through the Liard Rapids. Depending on run-off conditions as the time the diversion tunnel is closed, the rapids could be closed off as early as the first week in June or as late as the first

TABLE 5-10

COMPARISON OF LENGTHS OF NAVIGATION SEASON
IN LIARD RIVER AT LIARD RAPIDS UNDER NATURAL AND REGULATED CONDITIONS
FOR SAMPLE 10-YEAR PERIOD

Year	Non-regulated		Reservoir Filling (Predicted)				Reservoir Operation (Predicted)			
			Scheme 2		Scheme 8		Scheme 2		Scheme 8	
	Water too Low for Navigation Date	Navig. Season Days[*1]	Water too Low for Navigation Date	Navig. Season Days[*1]	Water too Low for Navigation Date	Navig. Season Days[*1]	Water too Low for Navigation Date	Navig. Season Days[*1]	Water too Low for Navigation Date	Navig. Season Days[*1]
1968	October 8	146	August 7	84	August 16	93	October 13	151	October 26	164
1969	July 24	70	June 5	21	July 16	62	June 15	31	August 14	91
1970	August 25	102	June 5	21	July 8	54	June 29[*2]	45	October 21	159
1971	July 30	76	July 19	65	July 22	68	July 27	73	September 19	127
1972	August 29	106	June 29	45	August 15	92	September 3[*3]	111	October 24	162
1973	September 21	129	July 19	65	August 5	82	September 30	138	August 5	82
1974	September 10	118	June 21	37[*2]	August 14	91	September 24	132	September 11	119
1975	August 31	108	July 22	68	August 16	93	September 5	113	October 12	150
1976	September 24	132	September 13	121	September 15	123	October 2	140	November 2	171
1977	September 3	111	August 6	83	August 18	95	September 14	122	October 20	158
Minimum	July 24	70	June 5	21	July 8	54	June 15	31	August 5	82
Maximum	October 8	146	September 13	121	September 15	123	October 2	140	November 2	171
Median	September 1	109	July 19	65	August 15	92	September 9	117	October 16	154

[*1] Assuming navigation commences 15 May.

[*2] River navigable for short intermittent periods following this date.

[*3] River not navigable for short intermittent periods before this date.

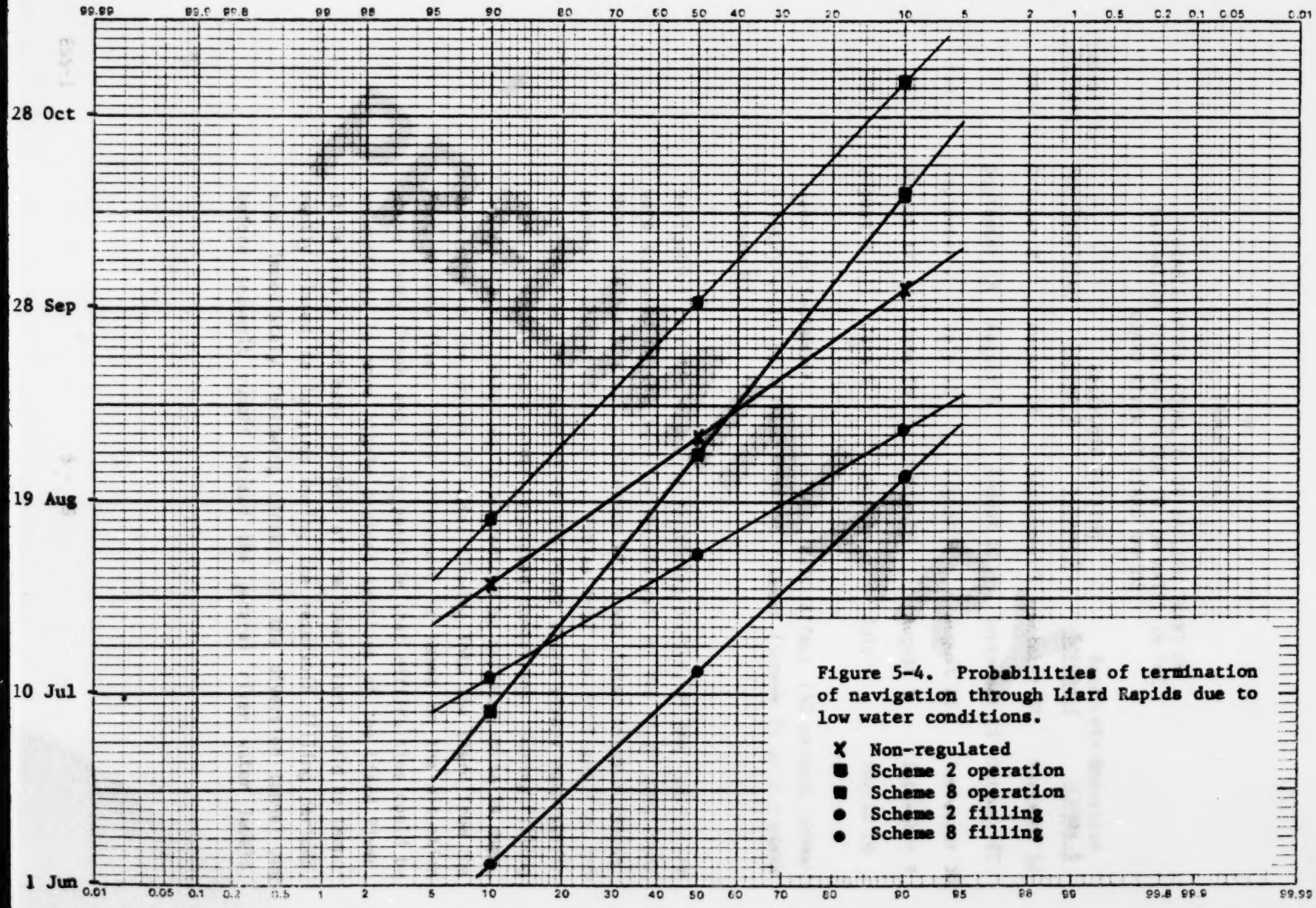


Figure 5-4. Probabilities of termination of navigation through Liard Rapids due to low water conditions.

TABLE 5-11

PROBABLE DATES (EQUAL TO OR EARLIER THAN) OF NAVIGATION TERMINATION DUE TO LOW WATER IN THE LIARD RIVER AT LIARD RAPIDS

Probability Percent	Non-Regulated	Reservoir Filling		Reservoir Operation	
		Scheme 2	Scheme 8	Scheme 2	Scheme 8
90	October 2	August 24	September 3	October 21	November 10
75	September 18	August 5	August 22	September 26	October 22
50	September 2	July 15	August 8	August 29	September 30
25	August 17	June 24	July 26	August 1	September 9
10	August 2	June 5	July 14	July 6	August 20

week in September. The most likely effect (50 percent probability) would be a reduction of 7 weeks (Scheme 2) or 3.5 weeks (Scheme 8).

Navigation conditions on the remaining portion of the lower Liard were assessed on the basis of an analysis of the river conditions above the Sandy Creek confluence which was taken to be a typical braided reach of the river. Tables 5-12 and 5-13 and Fig. 5-5 indicate that this portion of the river would always have sufficient navigable depth under regulated conditions. During filling the navigation season would be reduced by anything up to 14 days, depending on the amount of water flowing into the Liard from the Fort Nelson River. This assessment is based on the situation above Sandy Creek and it is possible that difficulties could be encountered in more highly braided sections of the Liard River. It is likely that many sections of the lower Liard would be temporarily closed to barging during the reservoir filling periods, e.g. immediately following closure of the diversion tunnel and before snowmelt runoff raised the general river water levels.

TABLE 5-12

COMPARISON OF LENGTHS OF NAVIGATION SEASON
IN LIARD RIVER ABOVE SANDY CREEK UNDER NATURAL AND REGULATED CONDITIONS
FOR SAMPLE 10-YEAR PERIOD

Year	Non-regulated		Reservoir Filling (Predicted)				Reservoir Operation (Predicted)			
			Scheme 2		Scheme 8		Scheme 2		Scheme 8	
	Water too Low for Navigation Date	Navig. Season Days[A1]	Water too Low for Navigation Date	Navig. Season Days[A1]	Water too Low for Navigation Date	Navig. Season Days[A1]	Water too Low[A2] for Navigation Date	Navig. Season Days[A1]	Water too Low[A2] for Navigation Date	Navig. Season Days[A1]
1968	November 8	177	October 29	167	November 6	175	-	-	-	-
1969	November 21	190	October 27	165[A3]	November 20	189	-	-	-	-
1970	November 27	196	October 9	147	November 27	196	-	-	-	-
1971	October 27	165	October 5	143	October 24	162	-	-	-	-
1972	November 4	173	October 26	164	November 2	171	-	-	-	-
1973	November 4	173	October 17	155	November 3	172	-	-	-	-
1974	November 9	178	November 4	173	November 8	177	-	-	-	-
1975	October 30	168	October 19	157	October 26	164	-	-	-	-
1976	November 19	188	November 16	185	November 19	188	-	-	-	-
1977	November 6	175	November 2	171	November 6	175	-	-	-	-
Minimum	October 27	165	October 5	143	October 24	162				
Maximum	November 27	196	November 16	185	November 27	196				
Median	November 6	175	October 27	165	November 6	175				

[A1] Assuming navigation commences 15 May.

[A2] Not limited by low water in Liard; navigation would probably be terminated by freezing of Fort Nelson River.

[A3] River not navigable for short periods before this date.

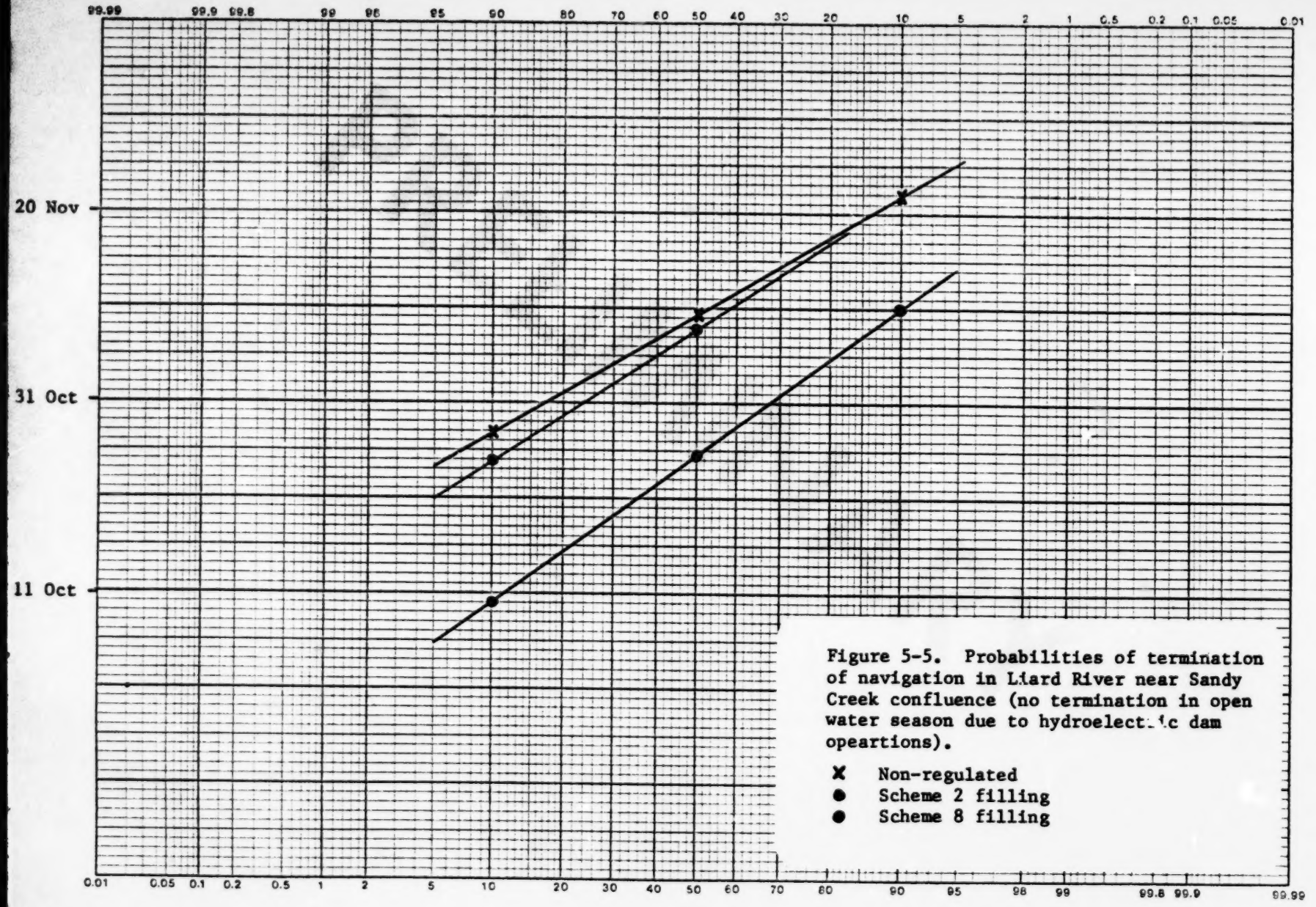

99.99 99.9 99.8 99 95 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
20 Nov
31 Oct
11 Oct
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
Figure 5-5. Probabilities of termination of navigation in Liard River near Sandy Creek confluence (no termination in open water season due to hydroelectric dam opeartions).
Non-regulated
Scheme 2 filling
Scheme 8 filling

TABLE 5-13

PROBABLE DATES (EQUAL TO OR EARLIER THAN) OF NAVIGATION TERMINATION DUE TO LOW WATER IN THE LIARD RIVER ABOVE THE SANDY CREEK CONFLUENCE

Probability Percent	Non-Regulated	Reservoir Filling Scheme 2	Reservoir Filling Scheme 8	Reservoir Operation Scheme 2*1	Reservoir Operation Scheme 8*1
90	November 22	November 10	November 22	-	-
75	November 16	November 2	November 15	-	-
50	November 9	October 25	November 8	-	-
25	November 3	October 16	November 1	-	-
10	October 28	October 10	October 25	-	-

*1 Not limited by low water condition in Liard; navigation would probably terminate due to freeze-up in Fort Nelson River.

Water levels in the Mackenzie River in 1980 were reported to have been the lowest in 45 years (Edmonton Journal 1981). As a result large operators such as NTCL and Arctic Transportation were forced to reduce operations to about 60 percent or normal capacity. The year 1980 is thus a useful reference against which to compare conditions as they might exist under Liard River flow regulations.

Table 5-14 compares predicted lowest monthly water levels for the sample period 1968 to 1977 at San Sault, Fort Good Hope and Norman Wells on the Mackenzie, and Fort Liard on the Liard with levels measured at these points in 1980 by Water Survey of Canada. The mean lowest monthly levels under regulation or during filling measured at any of the four stations would not drop as low as occurred in 1980. At difficult points such as San Sault even the most severe condition (Scheme 2 filling period) would not have reduced water levels to 1980 recorded levels. At Fort Good Hope and Norman Wells water levels during reservoir filling (Scheme 2)

TABLE 5-14

COMPARISON OF PREDICTED LOWEST MONTHLY WATER LEVELS AT WATER SURVEY OF CANADA GAUGING STATIONS ON LIARD AND MACKENZIE RIVERS UNDER ASSUMED REGULATED AND FILLING CONDITIONS FOR SAMPLE PERIOD 1968 TO 1977 WITH LOWEST MONTHLY WATER LEVELS ACTUALLY RECORDED

Station	Flow Conditions	Mean Lowest Monthly Water Level*1 in Metres (Range)			
		July	August	September	October
Mackenzie River at San Sault	Natural Flow 1968 to 1977*2	5.3 (4.6 - 6.1)	4.9 (4.2 - 5.9)	4.2 (3.7 - 4.7)	3.8 (3.3 - 4.2)
	Natural Flow 1980*3	4.6	3.9	3.6	3.8*5
	Scheme 2 Regulation 1968 to 1977*4	5.0 (4.3 - 6.1)	4.8 (4.3 - 5.2)	4.3 (3.9 - 4.7)	3.7 (3.4 - 4.3)
	Scheme 2 Filling 1968 to 1977*4	4.8 (4.2 - 5.3)	4.4 (4.0 - 5.3)	4.0 (3.6 - 4.4)	3.5 (3.2 - 4.0)
	Scheme 8 Regulation 1968 to 1977*4	5.8 (4.9 - 6.8)	5.1 (4.4 - 6.1)	4.0 (4.1 - 4.8)	3.9 (3.6 - 4.5)
	Scheme 8 Filling 1968 to 1977*4	5.1 (4.3 - 5.8)	4.6 (4.1 - 4.8)	4.1 (3.8 - 4.5)	3.6 (3.3 - 4.1)
Mackenzie River at Fort Good Hope	Natural Flow 1968 to 1977	3.6 (2.4 - 4.6)	2.7 (2.0 - 4.3)	1.9 (1.2 - 2.4)	1.2 (0.1 - 2.0)
	Natural Flow 1980	2.3	1.4	0.9	0.2
	Scheme 2 Regulation 1968 to 1977	3.2 (2.0 - 5.0)	2.8 (1.9 - 4.7)	2.0 (1.3 - 2.6)	1.0 (0.5 - 1.5)

TABLE 5-14 - (Cont'd)

Station	Flow Conditions	Mean Lowest Monthly Water Level*[1] in Metres (Range) July	August	September	October
	Scheme 2 Filling 1968 to 1977	2.8 (1.8 - 4.0)	2.2 (1.4 - 3.6)	1.4 (0.8 - 2.1)	0.6 (0.1 - 1.4)
	Scheme 8 Regulation 1968 to 1977	4.4 (2.9 - 5.8)	3.3 (2.2 - 5.0)	2.3 (1.6 - 2.9)	1.3 (0.9 - 2.2)
	Scheme 8 Filling 1968 to 1977	3.2 (2.0 - 4.4)	2.0 (1.6 - 4.0)	1.7 (1.1 - 2.3)	0.8 (0.4 - 1.7)
Mackenzie River at Norman Wells	Natural Flow 1968 to 1977	4.9 (4.3 - 5.8)	4.3 (3.8 - 5.4)	3.9 (3.4 - 4.2)	3.2 (2.9 - 3.7)
	Natural Flow 1980	4.7	4.2	4.0	3.8
	Scheme 2 Regulation 1968 to 1977	4.8 (4.3 - 5.2)	4.7 (4.3 - 5.2)	4.3 (4.0 - 4.5)	3.8 (3.5 - 4.1)
	Scheme 2 Filling 1968 to 1977	4.7 (4.2 - 5.0)	4.4 (4.0 - 5.0)	4.0 (3.6 - 4.3)	3.8 (3.5 - 4.1)
	Scheme 8 Regulation 1968 to 1977	5.1 (4.7 - 5.4)	4.8 (4.4 - 5.2)	4.5 (4.2 - 4.7)	4.0 (3.7 - 4.5)
	Scheme 8 Filling 1968 to 1977	4.8 (4.3 - 5.1)	4.5 (4.1 - 5.1)	4.2 (3.8 - 4.5)	3.6 (3.3 - 4.0)
Liard River at Fort Liard	Natural Flow 1968 to 1977	4.0 (3.1 - 5.3)	3.2 (2.5 - 4.5)	2.9 (2.5 - 3.5)	2.3 (1.9 - 2.7)
	Natural Flow 1980	4.4	3.6	3.4	3.1

TABLE 5-14 - (Cont'd)

Station	Flow Conditions	Mean Lowest Monthly Water Level*1 in Metres (Range) July	August	September	October
	Scheme 2 Regulation 1968 to 1977	3.2 (2.2 - 5.1)	3.4 (2.0 - 4.6)	3.0 (2.6 - 3.6)	2.6 (2.4 - 2.9)
	Scheme 2 Filling 1968 to 1977	2.6 (2.1 - 3.5)	2.4 (2.0 - 3.0)	2.2 (1.9 - 2.5)	2.0 (1.9 - 2.1)
	Scheme 8 Regulation 1968 to 1977	5.3 (4.2 - 6.8)	4.6 (3.1 - 4.7)	3.4 (3.1 - 3.7)	3.0 (2.5 - 3.5)
	Scheme 8 Filling 1968 to 1977	3.3 (2.6 - 4.4)	2.6 (2.3 - 3.7)	2.5 (2.3 - 2.8)	2.0 (1.9 - 2.5)

*1 Level as recorded on WSC gauge (note - not the level in the shipping channel).

*2 Data from Water Survey of Canada (1968 to 1977).

*3 Data from Water Survey of Canada (1981).

*4 Predicted Levels.

*5 Records available to 14 October.

would drop to the 1980 levels in about 1 year in 10 on average, and more seldom than this under regulation. The Liard River's flows in 1980 were slightly higher than the long-term average and had the proposed hydroelectric development been in place in 1980 the low flow problems along the Mackenzie would have been alleviated by the turbine releases in August, September and October.

5.3 OTHER CONDITIONS

Apart from ice and low water, impedences to navigation under non-regulated conditions include hazards from logs and uprooted trees being swept downstream during peak floods in July and sudden low flows in late fall brought about by ice formation. Although these factors could well be changed by flow regulation on the Liard River the present information base is too meager to permit adequate evaluation. Much of the debris in the Liard appears to originate within the Fort Nelson and Muskwa river basins (Grey 1978) which would not be affected by hydroelectric impoundments of the upstream Liard River. Overall effects of impoundment would be to reduce the spring and summer floods and this would have a tendency to reduce the amount of log debris entering the river.

SECTION 6.0 - DISCUSSION

Delays of 1 to 2 weeks in commencement of navigation on the lower Liard and up to 1 week on the Mackenzie because of changes in spring break-up have been tentatively predicted. Because of the more pronounced changes in ice volumes and river flows expected in the lower Liard, the delays in break-up can be predicted with a higher degree of certainty. Delays in break-up on the Mackenzie are subject to more uncertainty. More detailed studies on the ice regime or the Liard and Mackenzie are in progress and may provide the basis for a more definitive assessment of navigational impacts.

The reservoir filling period would constitute the period of major impact on the navigation season and the amount of impact produced would depend on river flow conditions in that year. However, the expense of dam construction and the large amounts of electrical energy produced would make it highly uneconomical to delay closure of the diversion tunnel even if flow conditions were substantially lower than normal. The filling period would reduce the navigational period through the San Sault Rapids from its present 59 to 113 days (10-year estimates) to 33 to 107. Under very low water conditions the San Sault Rapids would remain open only during June; under favourable water conditions this could extend through until mid-September. Access to the Norman Wells wharves, as they presently exist, would be available through early September if filling coincided with a low water year; it could extend through to freeze-up under favourable conditions. Navigation through the Ramparts Rapids would be reduced by a week or less under filling conditions.

The filling period could potentially control navigation through the Liard Rapids for an entire season if tunnel closure coincided with a low water year. The reaches above the rapids would remain generally navigable until freeze-up, even under such conditions. Under average flow conditions the Liard Rapids could be negotiated until mid-July.

Navigation on the Mackenzie River under regulated conditions could be curtailed or lengthened, depending on annual snowpack conditions throughout the basin. Regulation of the Liard under Scheme 2 development would in most years restrict navigation through the Liard Rapids. Under low water conditions, and assuming full dam operation, this could be limited to mid- and late July. It could extend through September or early October under more favourable conditions. Scheme 8 development would lead to an extension in navigational time through the Liard Rapids. The Liard River above the rapids would likely remain open under regulated conditions and navigation would likely be terminated by freeze-over of the Fort Nelson River.

The impacts on supply of goods to the river-based communities, exploration camps and other localities along the Liard and Mackenzie rivers would vary from year to year, depending on flow and ice conditions in the rivers. The most severe effect on Liard valley communities such as Fort Liard would be filling of the Site E reservoir in a year of relatively low flows in the major lower Liard tributaries. Ice break-up might be delayed for a period up to 2 weeks and would delay commencement of the navigation season. Under these conditions the period in which barges could supply Fort Liard or Nahanni Butte would probably be limited to about 16 or 17 weeks (late May to early September). This would be adequate time in which to supply these communities, especially since the curtailed shipping period would be anticipated in advance. River transportation beyond the Liard Rapids to Fort Simpson might not be possible under these severe circumstances. Supply of goods to Fort Simpson would not be affected, however, although late season shipment of heavy cargo from Fort Simpson up the Liard would not be possible. Filling of a Site G reservoir (Scheme 8) would not produce as severe an effect, nor would normal river regulation under Scheme 2 or Scheme 8 development.

Supply of goods via barge to Mackenzie river-based communities could be curtailed by a combination of delayed break-up and early low-water conditions. Delayed break-up and persistence or severe ice conditions

might delay barges reaching Fort Simpson and communities further downstream from Hay River by up to 2 weeks. There would be little measurable delay at communities such as Arctic Red River and Inuvik since barges proceeding downriver from Hay River would normally arrive there some weeks after break-up. Supply of equipment and bulk fuels from Inuvik to upriver locations might be delayed by 1 to 2 weeks. A combination of low water conditions and Site E reservoir filling could close the San Sault Rapids to northbound traffic by the beginning of July and thus cut Inuvik, Arctic Red River and possibly Tuktoyaktuk off from further bulk supplies. A combination of severe ice and low water conditions coinciding with Site E reservoir filling could thus restrict barge supplies from the south to Inuvik and Arctic Red River to a 2-month period (mid-June to early August). There is a low probability of such an occurrence of circumstances, however. The most likely combination of circumstances under Scheme 2 river regulation would see a normal river-based supply season for all communities south of San Sault rapids, including Norman Wells and Fort Simpson.

An important factor in alleviating navigational impacts of hydroelectric development is the predictability of water levels and, possibly, ice conditions. The Liard basin is presently supplied with six snow courses (Inland Waters Directorate, n.d.) which already provide some basis for estimating Liard River depths of significance to navigation. For example, March snowpack depths at Cassiar and Summit Lake provide a useful estimate of the navigation season through the Liard Rapids (R^2=0.64, n=6). By the time the Liard project is developed a more detailed hydrometerological network likely will have been established which will permit prediction of seasonal water levels and ice break-up well in advance of each barging season.

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APPENDIX A

ESTIMATION OF DAILY TURBINE RELEASES, SITE A

PRELIMINARY

APPENDIX A
ESTIMATION OF DAILY TURBINE RELEASES, SITE A

Monthly turbine releases from Site A have been computed (Hydroelectric Design Division 1979) to provide optimum long-term energy output. The objective in this study was to generate an autoregressive time series representing the best estimates of daily flows throughout the year, given the following conditions:

1. The mean of the daily estimated flows in each month must equal the given monthly mean turbine releases.

2. Daily flows have to contain a random component to represent the day-to-day fluctuation in turbine releases from an operating plant.

If the mean monthly turbine releases are designated $\bar{R}_A$, $\bar{R}_B$, $\bar{R}_C$, ... for months A, B, C, ... then it is assumed that these flows correspond to the median days in each month, designated

$$\frac{N_A}{2}, \quad \frac{N_B}{2}, \quad \frac{N_C}{2} \quad .....$$

where N_A, N_B, N_C, ... are the numbers of days in months A, B, C, ... (refer Fig. A-1).

A line joining $\frac{N_B}{2}$ to $\frac{N_C}{2}$ has slope m_{BC}

$$\text{where } m_{BC} = \frac{\bar{R}_C - \bar{R}_B}{\frac{N_C}{2} - \frac{N_B}{2}}$$

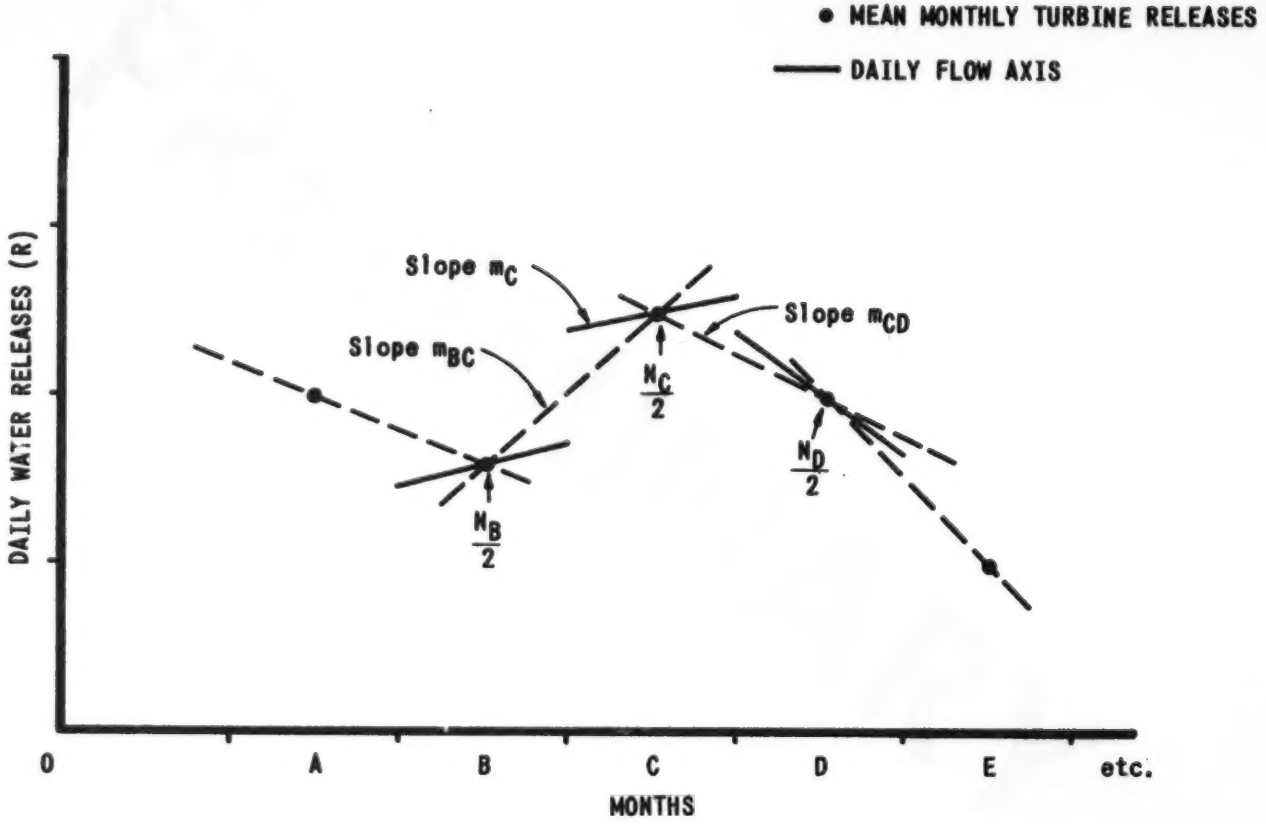


Figure A-I Method used to simulate daily turbine releases from Site A throughout the year, given mean monthly releases

similarly $m_{CD} = \dfrac{\bar{R}_D - \bar{R}_C}{\frac{N_D}{2} - \frac{N_C}{2}}$

The axis about which daily flows in month C will fluctuate can be taken to have slope m_C

where $m_C = \dfrac{m_{BC} + m_{CD}}{2}$

Daily turbine releases R_C in month C can now be computed as

$$R_C = I + m_C\, d_n + e$$

where I = an intercept term, computed as

$$I = \bar{R}_C - m_C\left(\frac{N_C}{2}\right)$$

and d_n = the date of each day n

$e \sim NID\ (0, S^2)$ is an error term generated randomly with zero mean and S^2 computed as

$$S^2 = \left[\frac{CV \cdot R}{100}\right]^2$$

CV is the coefficient of variation of the daily flows in each month and is arbitarily set at any level, e.g. 10 percent to represent the amount of day-to-day fluctuation in turbine releases.

If $R_C = I + m_C\, d_n + e$

then the monthly mean of the daily flows R_C can be calculated as

$$R_C = \sum_{t=1}^{n} R_{C_t} / N_C$$

where R_{C_t} is the daily flow series in month C and N_c = the number of days in month C.

This becomes

$$\Sigma\, (I + M_C\, d_n + e) \,/\, N_C$$

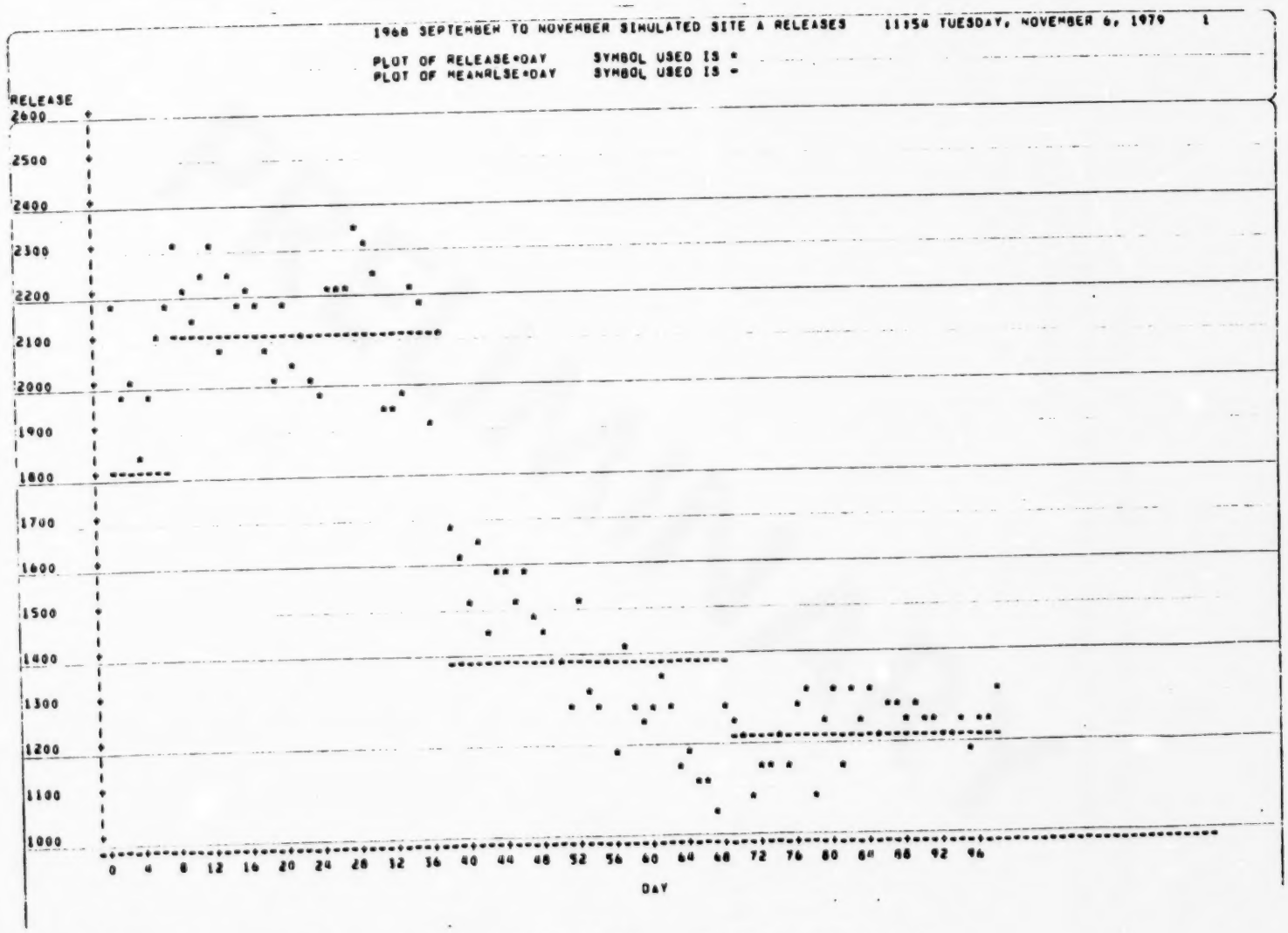
$$= (\Sigma I + \Sigma M_C d_n + \Sigma_e) \,/\, N_C$$

$$= (NI + m_C \cdot N \cdot \frac{NC}{2} + 0) \,/ N_C$$

$$= I + m_C \cdot \frac{NC}{2}$$

which is equivalent to R_C as orginally defined.

Fig. A-2 presents an example of daily releases estimated by this method and compares them to the mean monthly releases given.



m^3/s

Figure A-2. Example of simulated daily turbine releases from Site A compared to mean monthly release estimates.

APPENDIX B

Example of estimated daily stage reading at San Saults Rapids gauge (WSC) under non-regulated, regulated (Scheme 2) and reservoir filling conditions.

APPENDIX B

EXAMPLE OF STAGE READING AT SAN SAULT GAUGE, JULY TO NOVEMBER 1971
UNDER NATURAL, REGULATED AND FILLING (SCHEME 2) FLOW REGIMES

PLOT OF NATURAL*DAY SYMBOL USED IS *
PLOT OF REGULATE*DAY SYMBOL USED IS X
PLOT OF FILLING*DAY SYMBOL USED IS □